

**SEASONAL TRANSPORT OF NITRATE
INTO AND WITHIN A GROUND WATER AQUIFER**

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EXECUTIVE SUMMARY AND RECOMMENDATIONS

This work explores the non-point source pollution of the Mississippi River Alluvial Aquifer from nitrogen fertilizer applied in cotton production over a four-year period on the Macon Ridge in Louisiana. The study area is important agronomically as 40 percent of the cotton acreage in Louisiana is located on the Macon Ridge (Franklin, Richland, and West Carroll parishes). The Mississippi River Alluvial Aquifer underlies the Macon Ridge and serves as a sole source of water for many residents in rural areas. The primary purpose of this work was to demonstrate the extent to which conventional management practices in use on the Macon Ridge contaminate the aquifer with nitrate and provide alternative management practices which can prevent this contamination.

FINDINGS

Objective 1 - The calibrated NLEAP model successfully linked soil and climatic factors which affect the mobility of nitrate to the variable concentrations of nitrate observed in the aquifer.

Splitting rainfall into runoff and infiltration was a critical factor in obtaining agreement between model simulations and observed data. This parameter determines how much rainfall moves through the soil profile and was found to have the greatest impact in obtaining the most sensitive fit of the cyclic contamination of the aquifer.

While precipitation was the dominant force in the leaching process, the retention time of leachate in the clayey subsoil was identified as a major bottle-neck in regulating delivery of leachate to the aquifer.

Obtaining agreement between the nitrate concentrations observed in the 20 to 30 foot wells and what NLEAP delivered to the "hot zone", recognized as the Aquifer Mixing Volume (AMV), was empirical. We know from our observations in the multi-level wells that the "hot zone" exists and varies in thickness. Our intent was to simulate the nitrate concentrations that would end up in a domestic well screened at a shallow depth within the aquifer. A mechanistic approach to simulate a mixing of the "hot zone" intersecting a 10-foot well with uncontaminated water from below is beyond the scope of this work. However, an AMV 1.15 feet in depth not only yielded a good fit between the simulated and observed data, but closely approximates the one- to two-foot "hot zone" observed in the multi-level wells.

Objective 2 - The combination of a ground water tracer study and the use of wells screened in small increments helped us to identify the major processes that control movement of nitrate within the aquifer.

Hydraulic conductivity as related to lateral flow was found to be minimal if not undetectable in the upper reaches of the aquifer. We do not believe it is an important process in the dissipation of the high levels of nitrate contamination found in this extensive aquifer.

The process of dispersion was evaluated using nitrate distribution within the upper ten feet of the aquifer to evaluate the potential for deep mixing or dispersion of

nitrate contaminated water as a means of dilution. Our observations from the multi-level wells indicate that dispersion does occur but in a very heterogeneous manner due to the unpredictable nature of the braided stream sediment. Vertical mixing was definitively observed in one of the 30 to 40 foot wells, while absent in a second. While vertical mixing seems to be the most important process by which high nitrate levels found at the top of the aquifer are dissipated, it also points to deeper contamination of the aquifer than originally suspected.

Objective 3 - Two management practices were evaluated for their effectiveness in regulating factors or processes which determine the availability of nitrate to be leached.

The use of a split application of fertilizer was tested for its ability to reduce the amount of nitrate available for leaching during the early part of the growing season. The split fertilizer application did not prevent aquifer levels from exceeding the drinking water limit of 10 mg/L nitrate-N in both years tested. The single fertilizer application failed in both years as well. The point to be made is that a total of 80 lb/ac whether applied in a single or split application is excessive for the Gigger soil under a non-irrigated management system. Simulations of split and single fertilizer applications (60 lb/ac) indicated an overall reduction in nitrate contamination. However, only the split application (20 and 40 lb/ac) combined with a winter cover crop maintained aquifer nitrate-N levels below 10 mg/L.

The use of a winter cover crop of wheat was tested for its effectiveness in immobilizing residual nitrate over the winter season. The use of a winter cover crop

was effective in immobilizing residual soil-N, allowing aquifer nitrate-N levels to recover to well below contaminated levels (<5 mg/L). The capability of immobilizing soil-N is extremely important after dry growing seasons when potentially high levels of residual soil-N are left in the field and exposed to leaching as was the case in the winter following the 1995 growing season. No winter cover crop was used in this trial and exceptionally high levels of nitrate persisted in the aquifer throughout the spring and early summer.

APPLICATION

Our findings that nitrate contamination of the aquifer from which rural residents obtain water is occurring under conventional cotton management practices, should impress upon the agricultural community the responsibility they have for efficiently managing their use of N-fertilizers. Once they are aware of how easily nitrate can move into an aquifer from which their families obtain water, we feel they will be open to the idea of alternative management practices that can minimize this contamination to acceptable levels.

Our findings should also bring about an awareness in the agricultural research community that some of the fertilizer recommendations in current use need to be reexamined in light of both economic gain and environmental quality.

RECOMMENDATIONS

We strongly recommend the use of a winter crop as a BMP in the production of cotton. Not only has this management practice demonstrated its effectiveness in immobilizing residual soil-N left in the field after harvest, but in addition the use of a

winter cover crop is known to greatly reduce sediment loss from erosion. To efficiently manage N-fertilizer amendments, the amount of N being returned to the soil-N pool upon incorporation of the winter cover crop should be recognized in determining N fertilizer needs for the upcoming season.

Based on the observed data we cannot state that the use of a split fertilizer application will reduce the amount of nitrate leached into ground water. This BMP did not reduce nitrate-N levels in the aquifer below the 10 mg/L level at the rate applied. An ongoing investigation is examining the behavior of this BMP at a reduced application rate.

SEASONAL TRANSPORT OF NITRATE INTO AND WITHIN A GROUND WATER AQUIFER

1 INTRODUCTION

Farmers must meet the needs of an ever growing population and world market by maximizing crop yields with intensive management that incorporates irrigation, fertilization, and the use of pesticides. Despite the highly efficient management of land, reliance on such practices has increased the potential for non-point source pollution of the soil and groundwater (Burkart and Kolpin, 1993).

This work explores the possible non-point source pollution of the Mississippi River Alluvial Aquifer (MRAA) from nitrogen fertilizer applied in cotton production during a four-year period on the Macon Ridge in Louisiana (Figure1). The study area is important agronomically as 40 percent of the cotton acreage in Louisiana is located on the Macon Ridge (Franklin, Richland, and West Carroll parishes). The MRAA underlies the Macon Ridge and serves as a sole source of water for many residents in rural areas (Figure 2).

1.1 Background:

The presence of a high degree of interaction between the chemistry of the Mississippi River Alluvial Aquifer (MRAA) and the chemistry of the overlying soil environment of the Macon Ridge has been demonstrated (Walthall et al., 1992a; 1992b). A band of saline ground water occurring in the MRAA beneath the Macon Ridge was found to be responsible for high levels of exchangeable Na in the overlying

soil. A similar relationship was observed for the distribution of Cl as well. While recognizing this undesirable soil condition to be of an uncontrollable, natural origin, it is the high degree of interaction between the soil environment and the underlying aquifer that is alarming. We hypothesized that if the aquifer can have such an extensive regional effect in supplying unwanted levels of Na and especially Cl to these soils, in a similar manner, the soil environment may supply substantial levels of NO₃ to the upper regions of the aquifer where salinity levels are low and do not restrict domestic usage.

A close examination of the data of Whitfield (1975) supports this hypothesis. Based on the upper depth of the screened interval of the wells sampled; 8 of 33 wells (24%) at depths of less than 50 feet had NO₃ levels greater than 10 mg/L, 4 of 73 (5%) exceeded this level at depths between 50 and 100 feet, and 1 of 21 (5%) wells exceeded this limit at depths greater than 100 feet. This concentration of NO₃ in the upper portions of the MRAA strongly suggests that the contaminating source is being leached into the aquifer rather than being of an indigenous nature.

Guidelines in current use by the USDA Natural Resources Conservation Service (NRCS) in Louisiana (Water Quality Handbook. II-3 Soil Rating for NO₃ and Soluble Nutrients) allow for the determination of NO₃ leaching indices of specific soil types based on annual precipitation, hydrologic soil group, and rainfall distribution data. Three ratings are recognized in this system. The worst-case rating identifies situations in which NO₃ movement below the root zone will occur and recommends either intense nutrient management or no application. All of the 13 soil series recognized on the

Macon Ridge fall into this critical rating (Martin et al., 1980; and Soil Survey Staff, 1989).

As a follow-up study to the Na investigation of Walthall and Day (1992), a similar coring approach was used to examine the movement of NO_3 in cotton plots amended with 160, 80, and 0 lb/ac Urea-Ammonium-Nitrate (UAN). The 80 lb/ac rate is currently being recommended for cotton by the Macon Ridge Research Station. Some distinct patterns of NO_3 movement were identified: (1) substantial spikes of NO_3 were observed after major storm events in the 160 lb/ac treatment and (2) diffuse pulses occur during winter months in both the 80 and 160 lb/ac treatments. Although many questions have developed as a result of this study, it was clear that NO_3 from fertilizer amendments was being transported into the underlying aquifer.

1.2 Justification:

Nitrate is the most ubiquitous chemical contaminant in the world's aquifers and the levels of contamination are increasing (Spalding and Exner, 1993). The toxicity of NO_3 in drinking water has been in the public awareness for decades (U. S. Public Health Service, 1962). The maximum contaminant level for $\text{NO}_3\text{-N}$ in drinking water has been set at 10mg/L by the EPA (Dourson et al., 1991). One of the major health concerns linked to NO_3 in drinking water is methemoglobinemia, which can be fatal to infants under 6 months of age (Johnson et al., 1987).

Ground water is the source of drinking water for 90% of rural households and 75% of U. S. cities (Goodrich et al., 1991). The agricultural community is becoming increasingly aware of its role as a non-point source of surface and ground water

pollution. By incorporating strategic management programs into the farming operation a responsible balance can be achieved between economic production and maintenance of a sound environment. The purpose of this research is to integrate the soil profile and the underlying ground water aquifer of the Macon Ridge into a single system with respect to understanding the movement of nitrate originating as fertilizer amendments. This hydrologic integration must account for tremendous fluctuations in evapotranspiration, a loess-overlying-alluvium stratigraphy, discharge to and recharge from local streams, as well as the effects of density gradients of highly saline waters on dispersion rates. Integration of the soil and aquifer environments should provide an awareness for improved management practices involving the timing of application of agricultural chemicals and the need for monitoring water quality in sensitive regions on a seasonal rather than annual basis.

The MRAA is the major source of water for the Tensas River Basin consisting of nine parishes in the northeastern corner of Louisiana. In 1984, 400 wells were active in public, industrial, and agricultural use, with an estimated 14,000 in use for rural domestic use (Louisiana Department of Transportation and Development Office of Public Works, 1984).

Our concern is for the potential contamination of the MRAA beneath the Macon Ridge in northeast Louisiana. A north-south band running through the central part of this region is of particular concern because of high salinity levels occurring at relatively shallow depths in the aquifer. A common argument is that nitrate levels are dispersed before reaching the depths at which wells are screened. In some cases this may be

true; however, the density gradient between the highly saline water and the over-lying fresh water restricts dispersion. The depth at which domestic wells can be screened on the Macon Ridge is often limited by the quality of the ground water. Domestic wells are often screened at 20 to 40 feet to avoid saline water that is encountered at greater depths in the aquifer. The environmental concern is that as domestic wells are elevated to avoid salinity there is a strong possibility of pumping nitrate contaminated waters occurring at shallower depths. As pointed out by Keeney (1986), in most cases, contamination of only the upper portions of aquifers results from the activities of man.

1.3 Objectives

Objective 1 - Link soil and climatic factors which affect the mobility of nitrate to the variable concentrations of nitrate observed in the aquifer. The computer simulation model, NLEAP (Nitrate Leaching and Economic Analysis Package), (Schafer et al., 1991) was used for modeling nitrate movement from the soil surface into the aquifer. The advantage to using this mass balance model is that the various nitrogen pools can be examined throughout the year such that vulnerable situations can be identified. Once these critical periods are known, management strategies can be implemented to correct the situation.

Objective 2 - Identify processes that control movement of nitrate within the aquifer. Hydraulic conductivity as related to lateral flow was determined in the upper reaches of the aquifer to assess the potential for this process to dissipate high levels of nitrate contamination. The process of dispersion was evaluated using nitrate

distribution within the upper ten feet of the aquifer to evaluate the potential for deep mixing of nitrate contaminated water as a means of dilution.

Objective 3 - Evaluate two management practices for their effectiveness in regulating factors or processes which determine the availability of nitrate to be leached. The use of a split application of fertilizer was tested for its ability to reduce the amount of nitrate available for leaching during the early part of the growing season. The use of a winter cover crop of wheat was tested for its effectiveness in immobilizing residual nitrate over the winter season.

2 METHOD OF INVESTIGATION

2.1 BMP's Used

Research was conducted at the Macon Ridge Research Station near Winnsboro, Louisiana in Franklin Parish (Figure 1). Aquifer nitrate levels were observed under different Best Management Practices (BMP's) for cotton in: 1994 - single application of 80 lb/ac UAN (May 15) with a winter cover crop of wheat; 1995 - split applications of 40 lb/ac each UAN without a winter cover crop (May 15 and July 1); 1996 - single application of 80 lb/ac UAN (May 15) with a winter cover crop of wheat; and 1997 - split applications of 40 lb/ac each UAN without a winter cover crop (May 15 and July 1). The water table of the aquifer is approximately 20 feet below the soil surface. English units of measure are used throughout this report to aid in technology transfer to the end client, the cotton producer. All data input and output from the NLEAP model are expressed using this convention.

2.2 2-inch Wells

Two well sites, each consisting of 12 wells, four each screened from 20 to 30 ft, 30 to 40 ft, and 40 to 50 ft (2-in diameter PVC), were drilled using a hollow stem auger rig (Figure 3) provided by the United States Geological Survey (USGS). The two well sites are approximately 250 ft apart. Figure 4 is a diagram of the well installation protocol. The boreholes were filled with sand to cover the well screen. Bentonite was placed on top of the sand to seal off the screen, followed by a bentonite-cement grout to 24 in from the surface. A 6-in diameter casing with a screw cap was then inserted around the well 20 in below the soil surface.

The 6-in casing protected the well which was buried so that planting, fertilizing, spraying, etc. could be completed across the site. Opening the wells for sampling was accomplished by excavating the buried well and adding a 60-in PVC riser. The wells were closed and buried each April. The wells were then opened, sampled, and closed in June. In July the wells were reopened for the duration of the growing season.

2.3 Sample Collection

Water samples were collected bi-monthly using a submersible pump (Figure 5). Three well volumes were purged from the well prior to sample collection to remove free standing water in the well and insure sampled water represented ambient groundwater. Water was then collected in 175-mL Nalgene HDPE sample containers. Samples were placed in an ice chest and transported to the laboratory for analysis by ion chromatography.

2.4 Multi-level Wells

Multi-level monitoring wells were installed at the site in April of 1996 to observe the vertical and horizontal extent of nitrate mixing. These wells were also used to aid in determining chemical dispersion, hydraulic gradient, and mixing within the 20 to 30 ft screened wells. The multilevel sampling wells were developed by combining elements from previous investigations (Hansen and Harris, 1974; Barker et al., 1987; and Pickens et al., 1978). Each multilevel sampling well consisted of six, 0.5-in PVC wells. Each well had a 12-in screen. The six wells were spaced at 20-in vertical intervals (Figure 6). The multilevel sampling wells were installed at a depth of 31 ft and developed in the same manner as the larger screened wells. Water samples were collected using a

peristaltic pump (Figure 7). Three-well volumes were purged from each well before sample collection. Water samples were collected and stored in the same manner as described for the 2-in wells.

2.5 Tracer Study

The borehole dilution technique was used to obtain an estimate of the horizontal average of the linear velocity of groundwater (Freeze and Cherry, 1979). On January 17, 1997, two liters of a 50 mg/L Br solution were injected into a 20 to 30 ft screened well at the site. Sodium chloride, 0.75 g/L, was added to the bromide solution to increase the density of the solution to near aquifer conditions. The bottom 6.5 ft of the 10 ft screens were packed with latex balloons to limit the mixing zone of the Br tracer. The balloons were inflated by hand pump at the surface via a plastic tube. Samples were taken 30 minutes after the slug was introduced to determine the concentration at time 0, C_0 . For sampling, plastic tubing was lowered to the bottom of the well to retrieve a representative sample. The surface end of the tubing was closed with a clamp to hold the water column. The tubing was then pulled to the surface with the water column intact. The sample was flushed out with a pump. By using this sampling method a small amount of water was taken from the well with less disturbance than normal pumping. Samples were collected 3, 6, 9, 16, and 20 days after injection.

A copy of the original Quality Assurance Plan submitted in May of 1995 can be found as Attachment A at the end of this report.

3 RESULTS

3.1 Dispersion of Nitrate within the Aquifer

The following discussion summarizes our observations of nitrates in all of the monitoring wells from October of 1993 through March of 1998. This includes the 2-inch wells screened from 20 to 30 feet, 30 to 40 feet, and 40 to 50 feet; and the multilevel wells screened at six 1.5-ft intervals between 20 and 30 feet.

3.1.1 2 inch Wells

The 20 to 30 foot - 2 inch wells represent an average of the water column properties for the specified depth. We also assume these well samples represent the nitrate content of water that would be pumped from a shallow domestic well. A repeating, annual cycle is apparent for the 4-year observation period presented in Figure 8 for Site 1 and Figure 9 for Site 2. A cyclic trend stands out in all four of the wells at Site 1. This trend is present in the data of Site 2 but not so clearly in two of the wells. The reason is most likely due to poorer drainage in the soil at Site 2. The high and lows are very apparent at Site 1 and suggest faster transport of nitrate through this soil. The nitrate contamination at Site 2 does not reach the extremes of Site 1 but is spread out over a longer period of time. The wells at Site 2 are also slower and less successful at being purged of nitrate during the winter recovery period.

The cycle apparent in the well data begins with a flux of nitrate into the aquifer around the middle of July and reaches a peak in October and November. Elevated nitrate levels begin to decrease in December. Recovery of the aquifer occurs through the last sampling date (before the wells are buried for planting) in March or early April

as nitrate levels continue to drop. The initial contamination phase is observable in the first samples collected after the wells are reopened in late June or early July. With the first well observation in April of 1994 and the last in March of 1998, we have 4 years of data in which this cycle has repeated itself.

The worst case scenario was observed following the 1995 growing season when no winter cover crop was used, in which there was not enough leachate low in nitrate to dilute or flush high nitrate levels leached into the aquifer.

Possible mechanisms by which the high nitrate levels in the aquifer are dissipated beginning in December or January of most years would be a combination of lateral flow following the low gradient of the aquifer (found to be minimal, discussed later) and mixing and diffusion to greater depths. Nitrate data from one of the two 40-foot wells (Figure 10) indicate that diffusion and mixing does take place. The well from site 2 has peaks that coincide with the major contamination periods of the 30-foot wells. The 40-foot well from site 1 gives some indication of an increase of nitrate during this same period, but at very low concentrations (<2 mg/L). A peculiar behavior in the 40-foot well at site 2 is the manner in which the nitrate concentration of the well increases from year to year. The nitrate levels increase from 0.5 mg/L in 1993 and 1994 to 2 mg/L in 1995, to 4 mg/L in 1996, and to just over 10 mg/L in 1997/98. The contrasting behavior of the two 40-foot wells points to the heterogeneous nature of this braided-stream alluvial aquifer.

The two 50-foot wells give no indication of nitrate contamination over the observation period (Figure 10).

3.1.2 Multi-Level Wells

While the 2-inch wells present an averaging of the water column, the multi-level wells provide a more refined view of the heterogeneity of the water column (Figures 11 through 16). This heterogeneity can be extreme and is illustrated in Figure 15 for the multilevel well 2N in which nitrate-N levels fall below 15 mg/L for the most part throughout the observation period. However, with the exception of the 24-ft interval, the deeper wells (27-, 29-, and 31-foot) are at or near 10 mg/L nitrate-N, similar to the 22-foot well. This distribution of nitrate at depth suggests deep vertical mixing or diffusion. In contrast, multilevel well 2SW (Figure 16) has the most extreme nitrate-N levels observed ranging from 70 down to 30 mg/L. Furthermore, the evidence of deep vertical mixing of nitrate is absent with nitrate-N values at or below 5 mg/L in the 27-, 29-, and 31-foot wells. The 24-foot well follows the seasonal extremes but at much lower values below 10 mg/L. This heterogeneity should not be alarming considering the nature of the sedimentation process which built the Macon Ridge. It is considered to be a braided-stream terrace with coarse bands of sediment, varying in texture, being laid down by high velocity rivers carrying a heavy sediment load of glacial outwash. The degree to which this sediment body fits the true definition of a braided stream terrace seems to be something of an ongoing argument between geomorphologists. Our point is that the conductive pathways responsible for mixing and transport of the nitrate within the aquifer are highly unpredictable.

3.2 Linking Climate, Soil, and the Aquifer

The amount of nitrate ending up in a screened well within an aquifer is the product of a complex process which requires linking climatic conditions with soil and plant processes and transport to and movement within the aquifer. The nitrogen leaching model, NLEAP, was used to simulate and examine this complex system. A description of the how the model was set up and calibrated from choices offered in the model and inputs specific to the Macon Ridge Research Station follows.

3.2.1 Initial set up of model

3.2.1.1 Soil Parameters

Soil properties of the Gigger soil series (Figure 17) were selected from the SCS soil data base compiled to be used with the model. Soil parameters specific to the research site at the Macon Ridge Research Station follow:

Slope - 0%

Landscape position - summit

Restricting layer to rooting zone - 18 inches

Organic matter content of surface 6 inches - 0.5%

Initial Soil-N content

1994 - 15 lb/ac

Subsequent years - (1) residual soil-N from last month of previous year
plus (2) total crop uptake-N of wheat cover crop

Initial water content of soil

Surface 6 inches - 0.15 inches

Subsoil - 0.10 inches

3.2.1.2 Management Parameters

Crop Identification and planting and harvest dates

Cotton (5/1 - 9/15)

Cotton with Wheat Cover Crop (10/15 - 3/15)

Date of fertilizer amendments

Single (5/15)

Split (5/15 and 7/1)

CN - 89 (detailed explanation follows)

Tillage practices

Disc for Cotton Crop

Minimum till for Wheat Cover Crop

3.2.1.3 Climate Parameters

Monthly rainfall totals measured at the Macon Ridge Research Station are presented in Figure 18.

3.2.1.4 Aquifer Parameters

Shallow depth range - < 100 feet

3.2.2 Transport of Nitrate Leaving the Root Zone to the Aquifer

Calibration of the NLEAP model to observed well concentrations was based on three parameters. The cyclic behavior of nitrate-N concentrations in the aquifer was determined by the amount of precipitation entering the profile (CN) and the amount of

water needed to saturate the subsoil (bucket-size). The amplitude of the nitrate-N cycle was determined by the depth to which leachate was allowed to mix in the aquifer (AMV).

3.2.2.1 Splitting Rainfall into Runoff and Infiltration (CN)

The NLEAP model determines the amount of precipitation that infiltrates the soil profile and that lost to runoff using the method employed by the USDA-NRCS. This approach considers the permeability of the subsoil and how it would restrict drainage creating saturated conditions of the surface horizon such that additional rainfall would not be allowed to infiltrate but rather be lost to runoff. A series of curves were generated to reflect this distribution over a range of potential subsoil permeabilities. We found that using a curve number (CN) of 89 best fit out data regarding the timing of delivery of nitrate to the aquifer as well as the time at which the aquifer recovered. Figure 19 illustrates how the selection of the CN values can affect simulations.

3.2.2.2 Determination of Water Retention of Subsoil (Bucket)

The NLEAP model estimates the time it would take for leachate to move through the effective rooting zone which we defined as 18 inches based on root distributions observed in two excavated pits and numerous corings. The model calculates the amount of water (inches) needed to saturate the root zone (considering runoff, infiltration, evapotranspiration). When saturation of the root zone occurs, the leachate is available to move into the aquifer. However, the leachate must pass through the clayey subsoil, the fractured fragipan, and the stratified alluvial sands before entering the aquifer. We used the same "bucket" approach to simulate transport of leachate

from the root zone through this heterogeneous environment in the following manner. The subsoil "bucket" was limited to transport through the clayey subsoil. While a fragipan can be highly restrictive to leaching, the fractured nature of our fragipan allows for rapid preferential flow (Figure 20). The underlying sands below the fragipan were assumed to provide little if any restriction to water movement. The amount of water needed to saturate the subsoil of the Gigger soil was estimated in the Franklin Parish Soil Survey (1981) as 0.2 inches of water per inch of soil. The thickness of the clayey subsoil was determined from excavated pits to range from 25 to 30 inches. A subsoil thickness of 25 inches needing 0.2 in/in of water to leach yields a needed leaching volume of 5 inches of water. Monthly leaching volumes (Leaching Potential) simulated by NLEAP to leave the root zone were accumulated until the subsoil "bucket" was filled. When this criteria was met the total volume of leachate entering the subsoil "bucket" was leached into the aquifer. An example of how the size of the subsoil "bucket" determines the time at which transport of leachate into the aquifer occurs is given in Figure 21. Three subsoil "bucket" sizes are considered: 4, 5, and 6 inches. The delay in moving leachate into the aquifer is best illustrated in the 1995 growing season. The 4-inch bucket empties first in May resulting in a nitrate-N content in the aquifer of approximately 7 mg/L. The 5-inch bucket is not filled until August but delivers a higher concentration of nitrate-N to the aquifer of approximately 10 mg/L. The 6-inch bucket delivers a similar nitrate-N concentration but one month later. We selected the 5-inch bucket size for our model based on the best fit of the observed well data. The

criteria used in this selection of bucket-size focused on the delivery time of leachate entering the aquifer and recovery time afterwards.

3.2.2.3 Aquifer Mixing Volume (AMV)

The Aquifer Mixing Volume (AMV) is determined by the depth to which leachate carrying concentrated levels of nitrate-N is allowed to mix and be diluted within the aquifer. If contaminated leachate were allowed to mix to a depth of 10 feet, the length of 10-foot screens, the nitrate would be diluted to near background levels. However, as observed in the multi-level wells, a "hot zone" occurs in the top 1 to 2 feet of the aquifer and rapidly decreases. An example of how the choice of the AMV affects the amplitude of nitrate-N concentrations is illustrated in Figure 22 for AMV values of 1 and 1.25 feet. An AMV of 1.15 feet was determined to provide the best simulation of observed nitrate-N concentrations in the 20 to 30 foot wells. It is important to point out that the concentration of nitrate-N observed in the 20 to 30 foot wells is a mixing of the highly concentrated "hot zone" with lesser contaminated water extending to a depth of 30 feet. Therefore, the purpose of the AMV selection is to calibrate leachate concentrations with values observed in the 20 to 30 foot wells rather than the "hot zone" observed in the multi-level wells.

3.2.2.4 Final Calibration

The final calibration of the model to the observed well data is presented in Figure 23, in which a CN value of 89, a subsoil bucket size of 5 inches, and an AMV of 1.15 feet were used. We believe the model provides an excellent simulation of the observed nitrate-N concentrations in the 20 to 30 foot wells. The onset of aquifer contamination

and recovery are accurately predicted as well as the concentration of nitrate-N in the 20 to 30 foot wells. There is somewhat of a delay in the predicting the recovery of the wells during the winters in which a cover-crop was used (1994 and 1996). The model was very effective in predicting the inability of the wells to recover from nitrate contamination during the winter of 1995. While the model was accurate in estimating the high concentration of nitrate-N contamination (15 mg/L) in the summer of 1996, it was approximately 2 months premature in this effort.

3.3 Movement of Water within the Aquifer

3.3.1 Water-level Fluctuation Within the Aquifer

A critical factor affecting sampling of the "hot zone" by the multi-level wells, as well as the mixing of the "hot zone" in the 20 to 30 foot wells, is a fluctuation in the aquifer level in that it determines when the "hot zone" intersects the screened interval of the well. The water level of the aquifer was monitored from June of 1996 through June of 1998 (Figure 24). Water levels fluctuated 1.3 feet ranging from a high of 19.2 feet to a low of 20.5 feet. Shifting the "hot zone" over this range could increase or decrease its contribution to observed nitrate-N concentrations in the 20 to 30 foot wells. Aquifer levels began to decrease in July of 1996 and 1997, reaching a low point in November. Aquifer levels began to drop rapidly in April of 1998 reflecting the severe drought of this year. The typical draw down of the aquifer level in mid-summer coincides with maximum evapotranspiration limiting leachate during the height of the growing season and the onset of large quantities of water being removed from the aquifer through pumpage for irrigation.

3.3.2 Minimal Later-Flow Gradient

The borehole dilution method and water level measurements between wells were used to investigate the transport of nitrate laterally within the aquifer. By determining the lateral flow component of this system, the contribution of other possible nitrate sources upgradient could be included or omitted based on the rate of movement. An understanding of the lateral flow component also was important in determining the residence time of nitrate underlying the site.

There was no detectable difference in hydraulic head between wells (1 to 5 m apart) or well sites (75 m apart) during all three growing seasons. This should come as no surprise considering Whitfield's (1975) potentiometric surface map for the area shows a minimal (0.5 m/km) hydraulic gradient to the south.

The borehole dilution method, using bromide as a tracer, was used to determine the effects of linear advective flow in the aquifer. Two rates were calculated. The first rate is derived from the bromide concentration change between the first and third sampling days (0.06 cm/day). The second rate was determined from the third to fifth sampling date (0.34 cm/day).

The lateral flow values observed in this analysis are slower than the upper rate range for transport by diffusion, about 1 cm/day (Halevy et al., 1967), indicating that nitrate is not likely to be transported by lateral flow. Thus, nitrate increases in the aquifer underlying the study site must come from leachate high in nitrate recharging the aquifer from the surface.

The two Br concentration reductions we observed dictate that diffusion does not act alone. The differences in the two calculated values can be linked to physical changes in the aquifer. Aquifer water levels rose 2.4 in between the third and fifth sampling date indicating a recharge event was taking place. As a result, Br levels were diminished more rapidly due to diffusion and fresh leachate from the surface recharging the aquifer.

Because lateral movement within the aquifer is minimal, high levels of nitrate within the aquifer must be reduced by either diffusion alone or diffusion and dilution by leachate low in nitrate recharging the aquifer from the surface. As a result, aquifer nitrate levels should change slightly when diffusion acts alone. Major reductions in nitrate levels should occur when leachate low in nitrate recharges the aquifer as was observed in the Br analysis.

3.4 Evaluation of BMP's Used

Observations of nitrate-N levels in the 20 to 30 foot wells indicate variability among the wells, especially in well 2-21 that consistently had nitrate-N levels below the others. A minimal cycling effect in wells 2-24 and 2-25 were also suspicious. Although the wells were assumed to have been set at the 20 to 30 foot depth interval, a follow-up survey of well depths revealed that these three suspect wells were screened at a depth of 23 to 33 feet (Table 1). From the detailed observations made possible in the multi-level wells it is obvious that these wells are screened below the "hot zone" of nitrate located at the top of the aquifer. For the purpose of obtaining an average nitrate-N value of the 20 to 30 foot wells, these three suspect wells were not used. Out of the six

multi-level wells, well 1SE was found to be set approximately one foot higher than the others (Table 2). In most months, the shallowest of the multi-level wells was dry and no sample could be collected. The nitrate-N data for this incomplete depth interval is not presented.

The observed well data in Figure 23 indicate that the split fertilizer application of 40 lb/ac May 15 and 40 lb/ac July 1 in the 1995 and 1997 growing seasons did not prevent aquifer levels from exceeding the drinking water limit of 10 mg/L nitrate-N. The single fertilizer application of 80 lb/ac in May of 1995 and 1997 failed as well. The point to be made is that a total of 80 lb/ac whether applied in a single or split application is excessive for the Gigger soil under a non-irrigated management system.

In contrast, the use of a winter cover crop following the 1994 and 1996 growing seasons revealed that residual soil-N was immobilized over the winter (Figure 25), allowing aquifer nitrate-N levels to recover to well below contaminated levels (<5 mg/L). This potential is extremely important after dry growing seasons when potentially high levels of soil-N are left in the field and exposed to leaching as was the case in the winter following the 1995 growing season and exceptionally high levels of nitrate persisted in the aquifer. Incorporation of the winter cover crop in March releases the retained N for use in the following growing season. To efficiently manage N-fertilizer amendments, the amount of N being returned to the soil-N pool upon incorporation of the winter cover crop should be recognized in determining N fertilizer needs for the upcoming season.

3.4.1 Evaluation of BMP's Over a Continuous 4-year Period

The NLEAP model, calibrated to our 20 to 30 foot wells was utilized to demonstrate the advantages and disadvantages of the following management practices when used continuously over a 4-year period: Split - Cover, Single - Cover, Split - No Cover, Single - No Cover. The simulations use the rainfall for the 4-year period of 1994, 1995, 1996 and 1997. The soil-N content at the time of the first fertilizer application (80 lb/ac in the single application and 40 lb/ac in the first split application) was considered in determining the initial fertilizer application such that the total amount of N-fertilizer plus the initial soil-N present did not exceed the targeted rate. In some cases this reduced the initial fertilizer amendment by as much 20 lb/ac. The results of these simulated conditions are presented in Figure 26.

3.4.1.1 Single Fertilizer Application

The use of single fertilizer application with or without a winter cover crop provided the highest level of aquifer contamination during the 1995 growing season (19 to 23 mg/L nitrate-N). The single application with or without a cover crop provided the greatest degree of aquifer contamination in the remaining three years as well.

3.4.1.2 Split Fertilization Application

The lowest levels of aquifer contamination were obtained in the simulation of the split fertilizer application followed by a winter cover crop. The split application with no winter cover crop failed only in its ability to reduce aquifer contamination during the winter by immobilizing residual soil-N left in the field after harvest. This failure observed

in the well data following the 1995 season was eliminated in both winter cover crop simulations.

3.4.1.3 Reduced Fertilizer Amendment

It is again important to point out that even with both BMP's being utilized aquifer levels continue to approach 10 mg/L nitrate-N. The strongest conclusion to be made from these simulations is that a reduced rate of nitrate-N is needed for this combination of climate, soil, and aquifer conditions. We attempted to find how much of a reduction in total-N would be required to reduce aquifer levels below the 10 mg/L limit for nitrate-N. The simulation results of an initial 20 lb/ac split, followed by a second 40 lb/ac split, with a winter cover crop are presented in Figure 27. The results are promising in that aquifer contamination was reduced below the 10 mg/L limit, however, aquifer contamination was not eliminated. This 4-year simulation with a varied rainfall pattern provides a strong test involving contrasting precipitation inputs.

4 EDUCATIONAL OUTREACH

Results from this project have been disseminated in the following manner.

4.1 Publications

1. Walthall, P.M., W.D. Brady, and R.L. Hutchinson. 1995. Seasonal fluctuation in ground water nitrate in response to climate and cotton management practices. (Ed.) H.M. Selim and W.H. Brown. Proceedings. Conference on Environmental Issues. LSU Agricultural Center. Louisiana Agricultural Experiment Station. pp 149-152. **Attachment B**
2. Walthall, P.M., W.D. Brady, and R.L. Hutchinson. 1996. Cotton production on the Macon Ridge: how to reduce nitrate leached into drinking water? Louisiana Agriculture. LSU Agricultural Center. Louisiana Agricultural Experiment Station. Vol. 39, No. 2, pp. 5-9. **Attachment C**
3. Brady, W.D. 1997. Movement of nitrate into and within the Mississippi River alluvial aquifer. M.S. Thesis. Louisiana State University. Agronomy Dept. 125 pages.
4. Brady, W.D. and P.M. Walthall. 1998. The behavior of nitrate in the Mississippi River Alluvial Aquifer. Ground Water Monitoring and Remediation. (Submitted May 1998). **Attachment D**

4.2 Presentations

1. Brady, W.D. and P.M. Walthall. 1996. Dilution and dispersion of nitrate within the mixing zone of the Mississippi River alluvial aquifer. Agronomy Abstracts. American Society of Agronomy, National Meetings, Indianapolis, IN.
2. Walthall, P.M., W.D. Brady, and R.L. Hutchinson. 1995. Seasonal fluctuation in ground water nitrate in response to climate and cotton management practices. Conference on Environmental Issues. LSU Agricultural Center. Louisiana Agricultural Experiment Station. Baton Rouge, LA.
3. Brady, W.D. and P.M. Walthall. 1995. Seasonal movement of nitrate into and within the Mississippi River alluvial aquifer. Agronomy Abstracts. American Society of Agronomy, National Meetings, St. Louis, MO.
4. Walthall, P.M. 1994. Seasonal nitrate contamination of a shallow ground water aquifer. Ag Week Invited Speaker. College of Agriculture, Louisiana State University.

5 PROBLEMS ENCOUNTERED DURING THE PROJECT

The major problem encountered was in well installation and involved controlling the final depth at which the wells were set. In some cases errors could have been avoided by monitoring the well drilling depth, although a great level of confidence was maintained by the drill operators. Pushing the assembled well through the temporary plate situated at the bottom of the hollow stem auger can be difficult. If pushed with excessive force the well may penetrate further into the aquifer sand than realized. Once the aquifer sand caves in around the exposed well, the well is trapped in place. The skill to avoid these types of problems can only come with experience, which we now have.

In hindsight, the BMP trials would have been run concurrently so that each practice could be observed under the same climatic conditions, assuming that appropriate funding and space were available. In addition, a reduced N-application rate, 60 lb/ac in addition to 80 lb/ac, would be added. This approach would allow for a shorter observation period (2 years rather than 4) and allow for evaluating any reductions in yield resulting from the lower amendment rate. These modifications would increase the size of the research site by a factor of 8. The potential for introducing site variability would obviously be increased. The number of wells to be sampled would also be increased by a factor 8.

6 SHORT AND LONG TERM BENEFITS

The short term benefit of this work lies in providing conclusive evidence that the aquifer is being contaminated with nitrate from fertilizer amendments applied under the

currently recommended rate of 80 lb/ac. Further, we showed specifically when this contamination occurs and under what conditions it is likely to persist. This should aid in developing an immediate awareness that there is a problem that can be addressed through better management practices.

The long term benefit of this work demonstrates the advantage using a winter cover crop offers in protecting water quality and in conserving residual soil-N for use in the next growing season. This should aid in developing an awareness for considering the existing soil-N when determining additional fertilizer amendment rates. Although, the benefit of using a split application to reduce the amount of time fertilizer amendments are exposed to leaching before crop uptake was not apparent at the currently recommended rate of 80 lb/ac, model simulations did indicate that this BMP would be realized if the total amount of the split application were reduced. Further, this work should develop in time an awareness among producers that they can control the contamination of their drinking water by utilizing management practices available to them.

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Figure 17. Soil profile of the Gigger series recognized at the well site. The white marks on the tape are in 10-cm increments.

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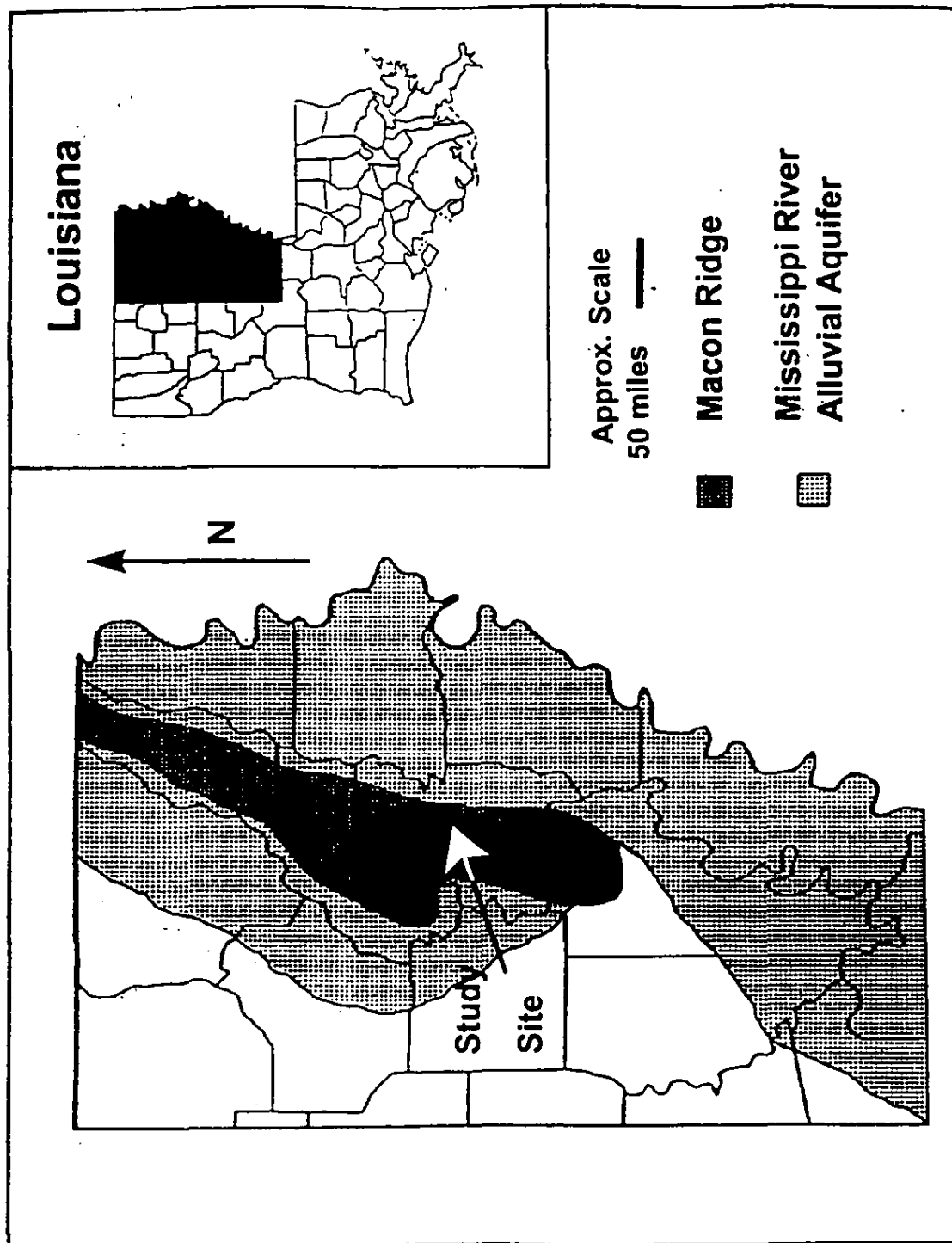


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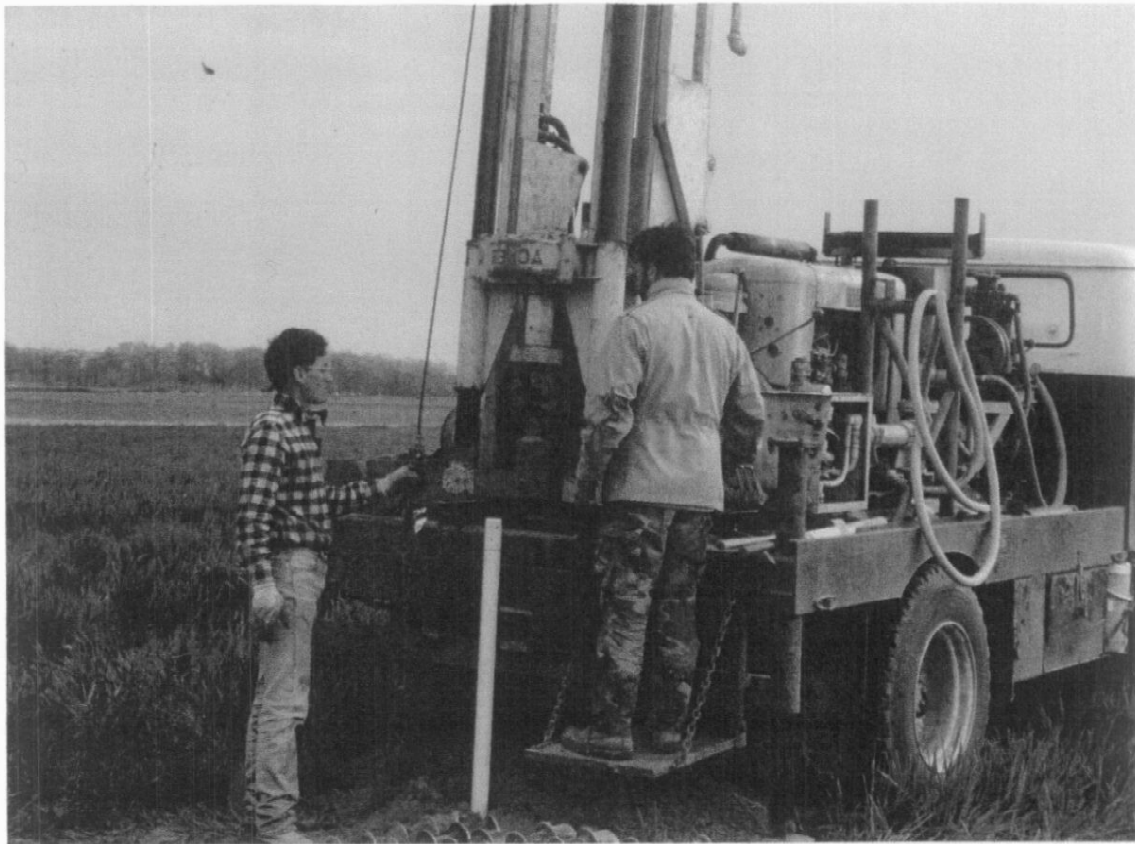


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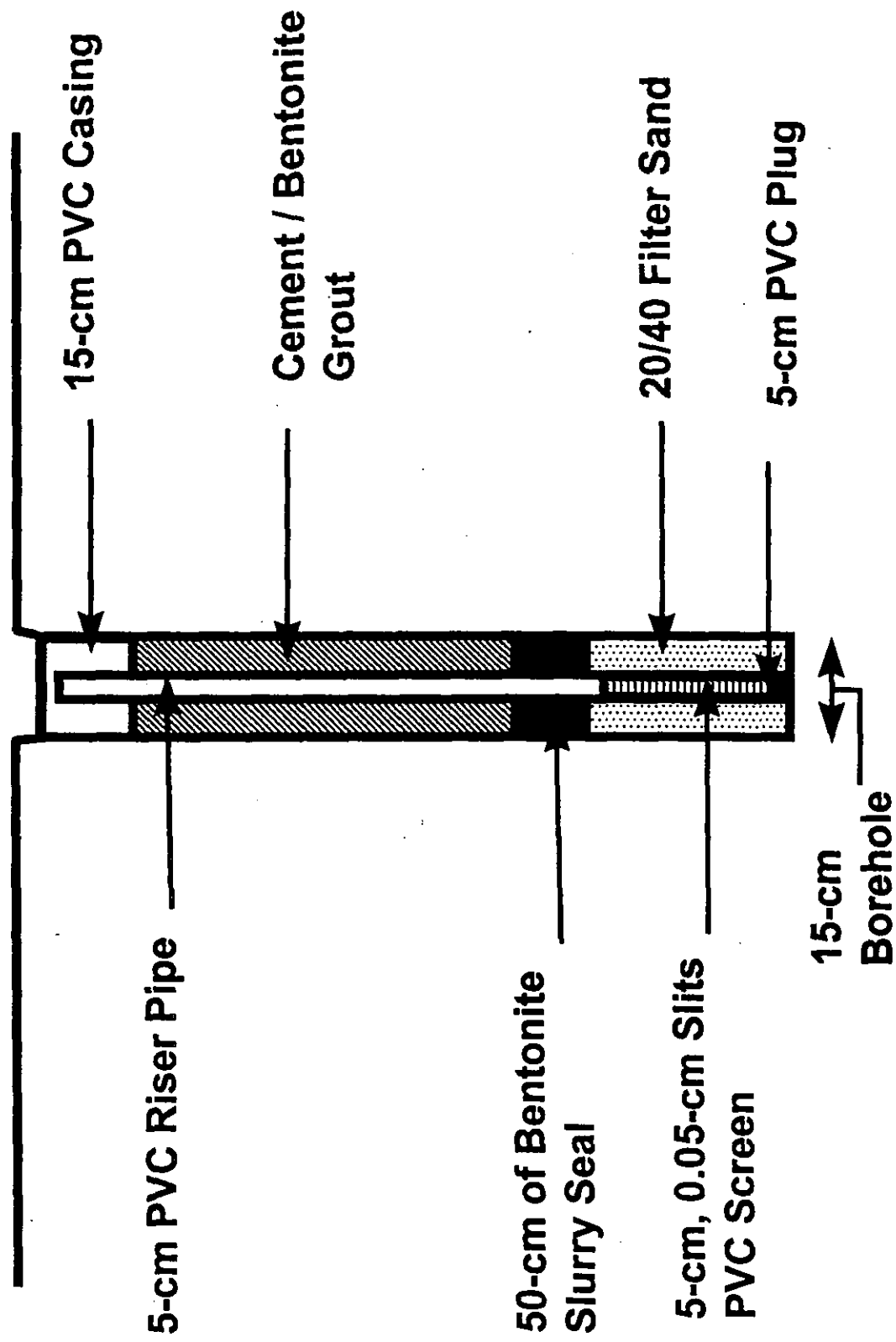


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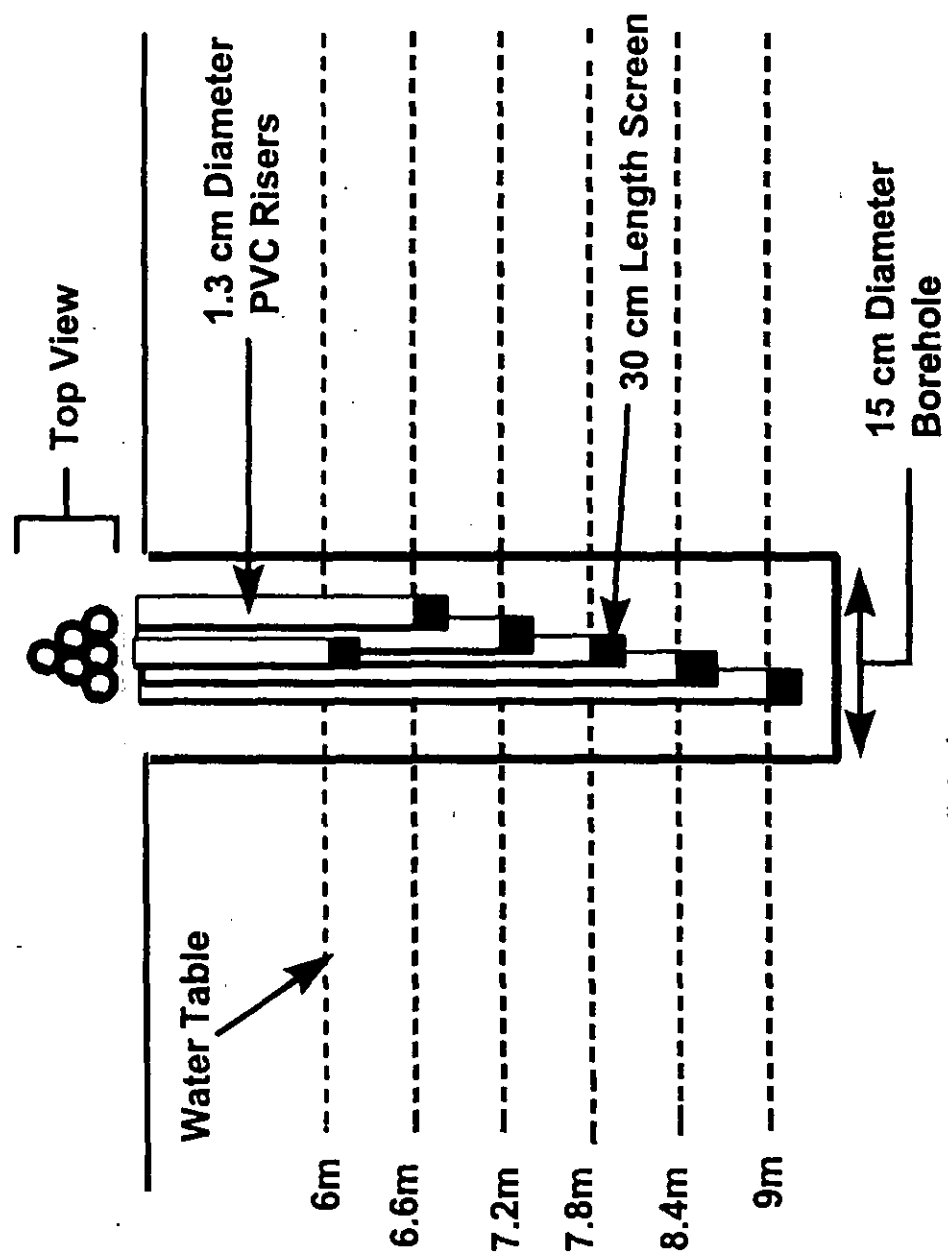


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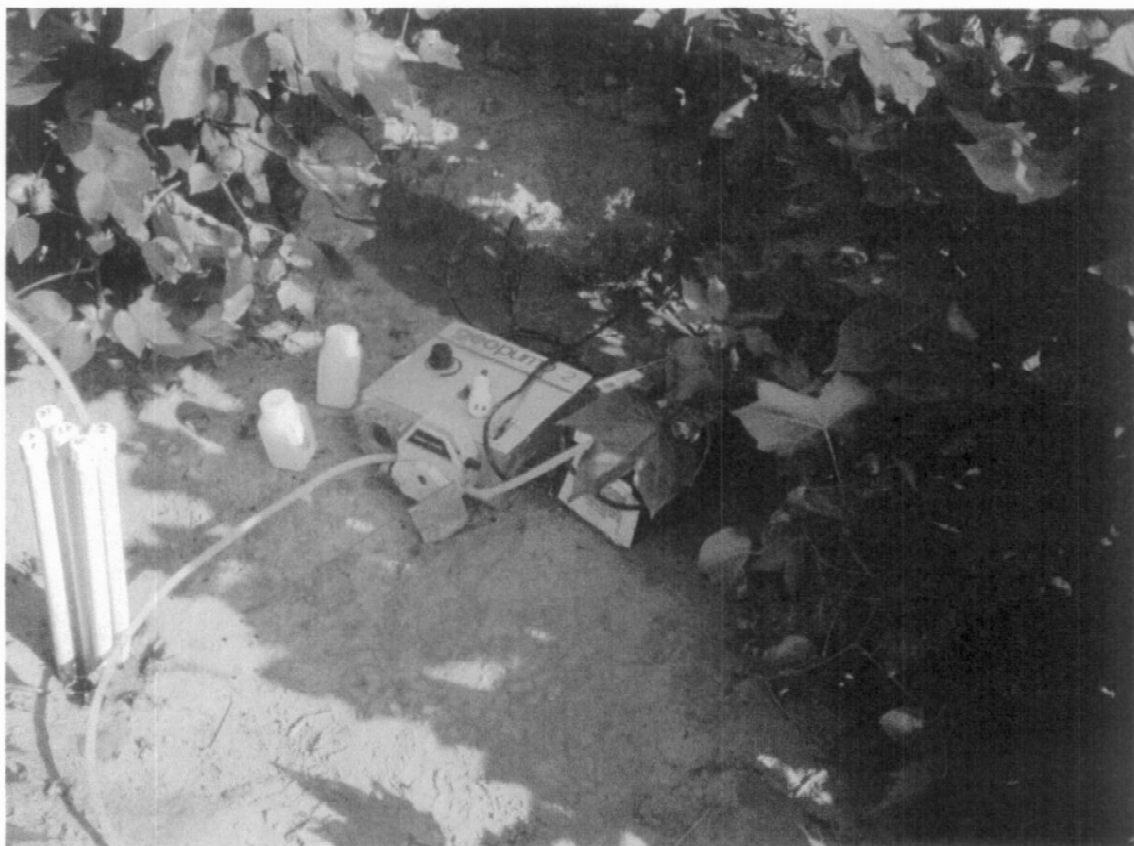


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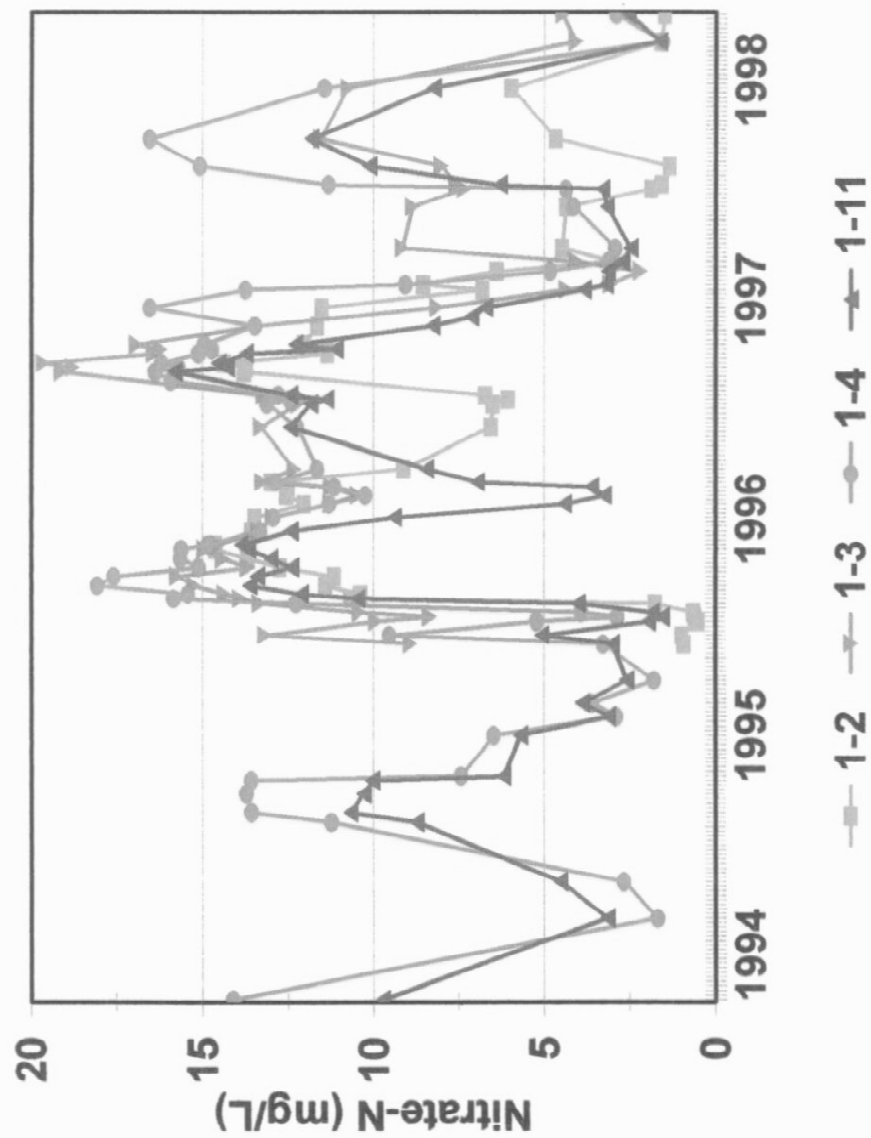


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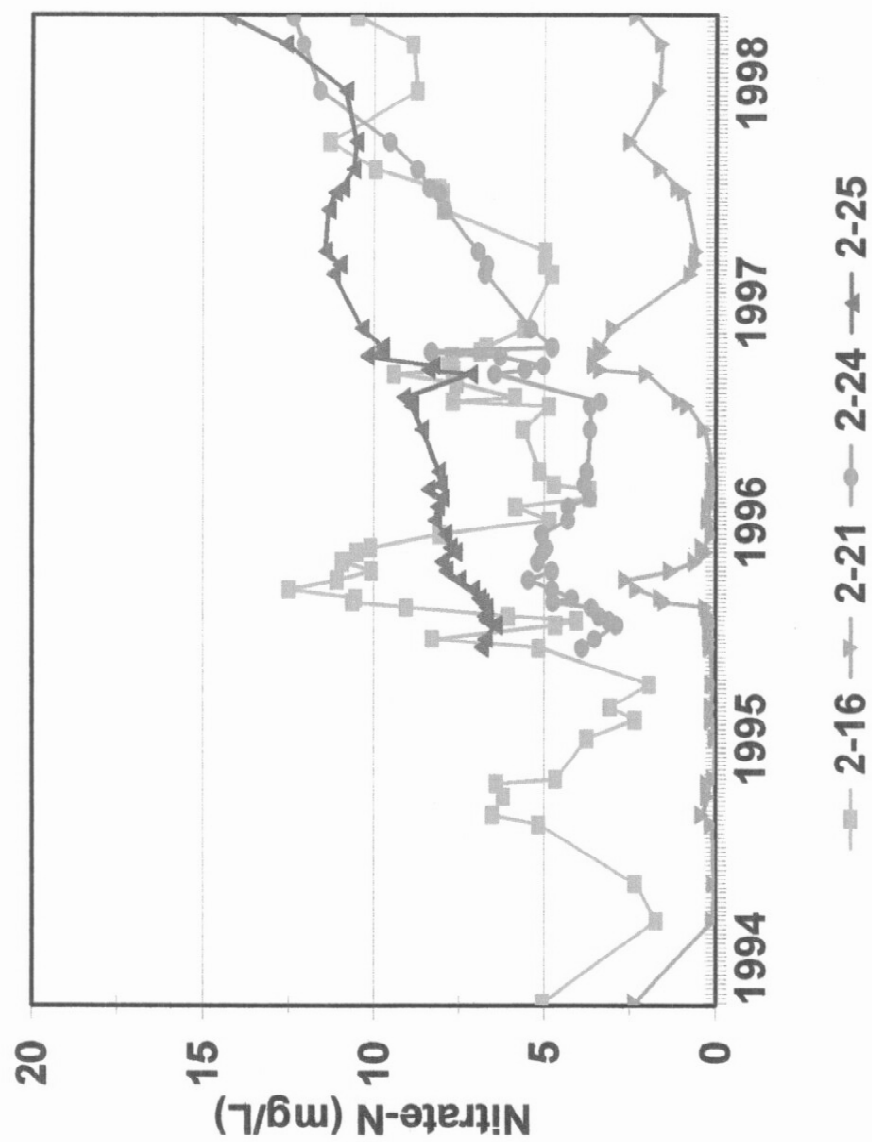


Figure 9. Nitrate-N concentrations observed in 20 to 30 foot 2-inch wells at Site 2.

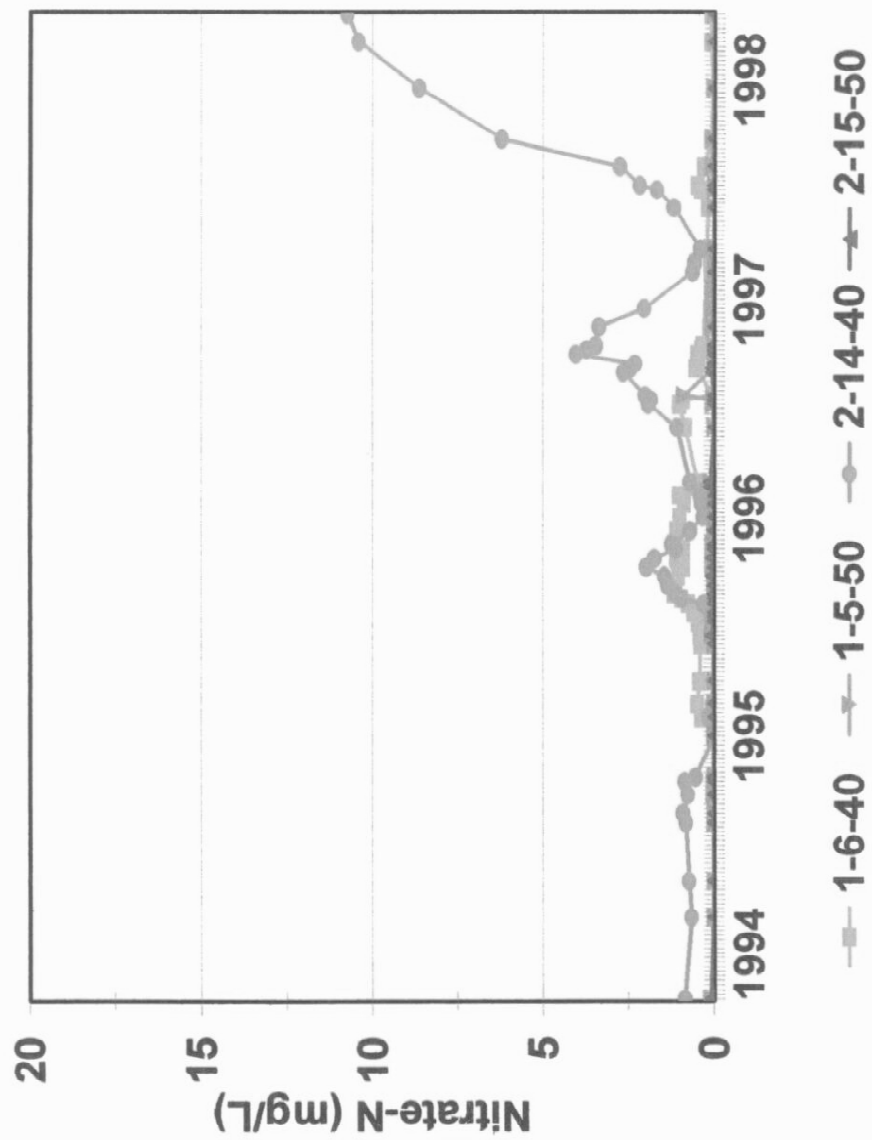


Figure 10. Nitrate-N concentrations observed in 30 to 40 and 40 to 50 foot 2-inch wells at Sites 1 and 2.

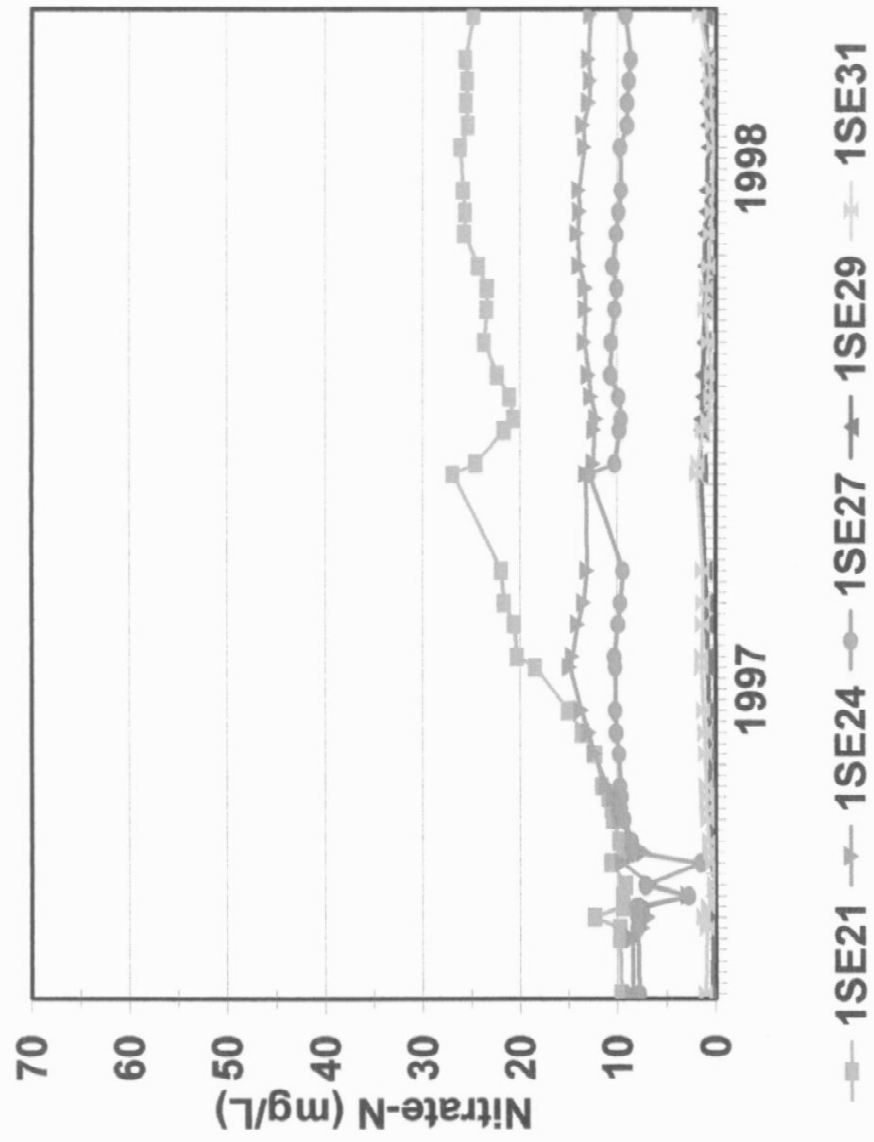


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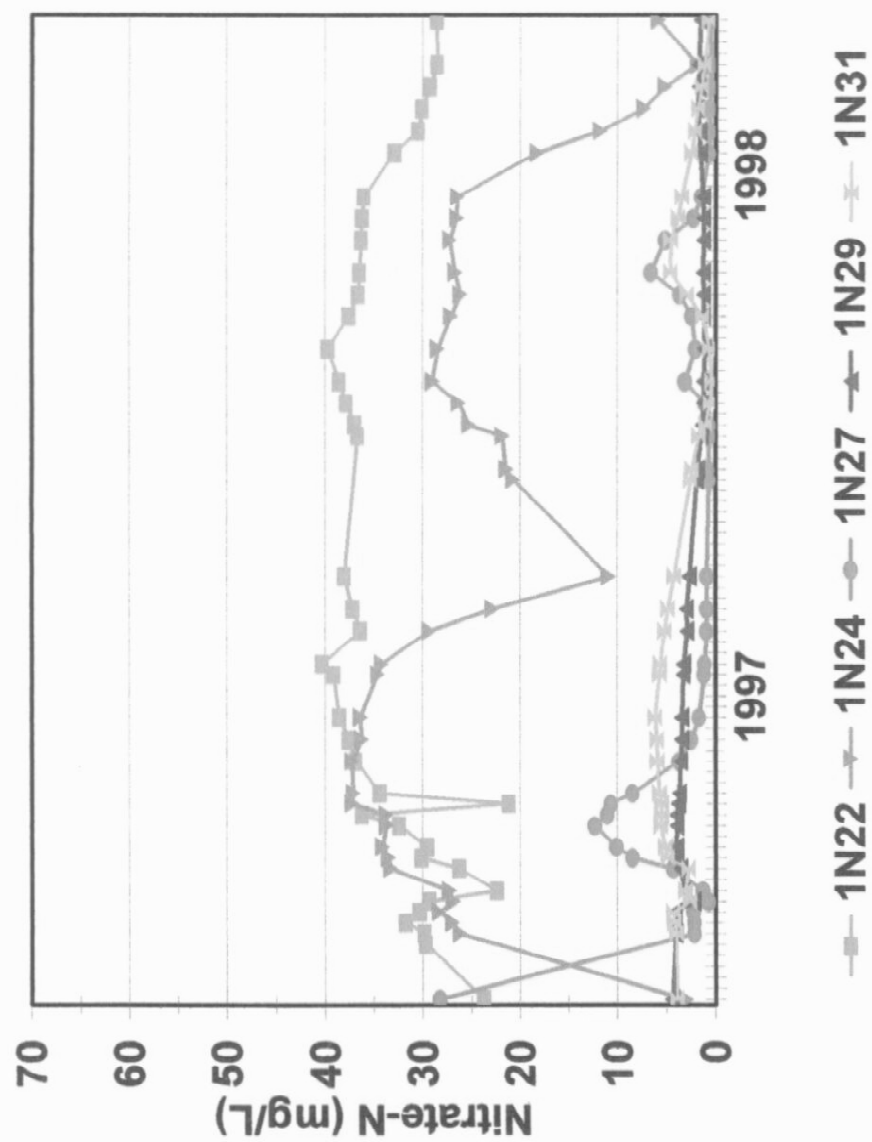


Figure 12. Nitrate-N concentrations observed in multi-level well 1N from Site 1.

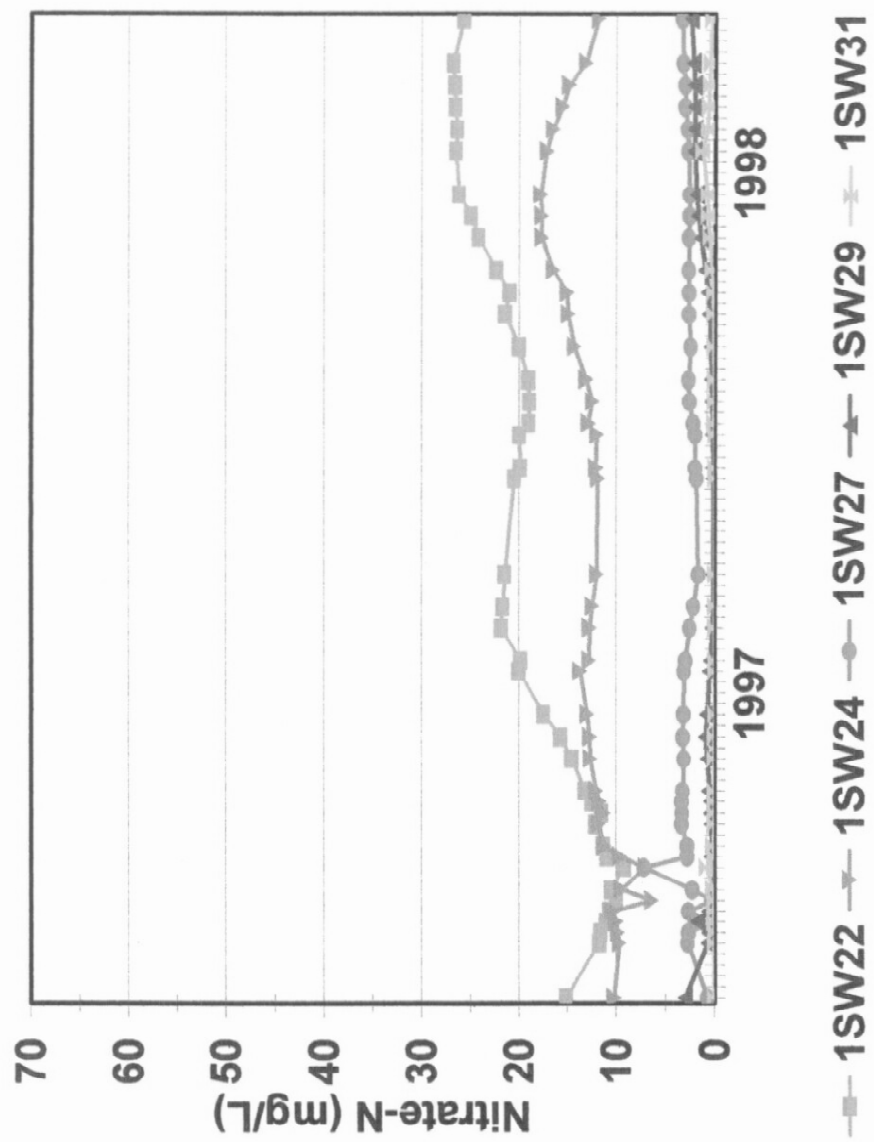


Figure 13. Nitrate-N concentrations observed in multi-level well 1SW from Site 1.

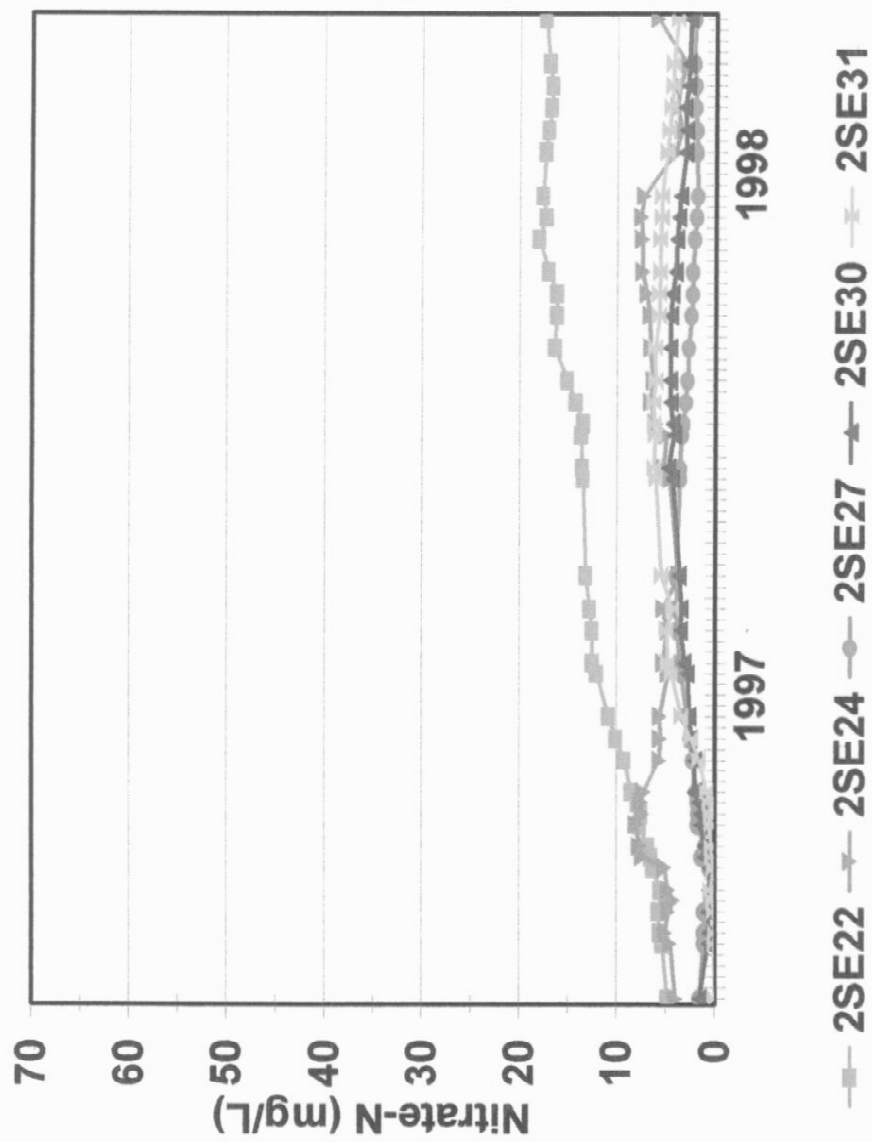


Figure 14. Nitrate-N concentrations observed in multi-level well 2SE from Site 2.

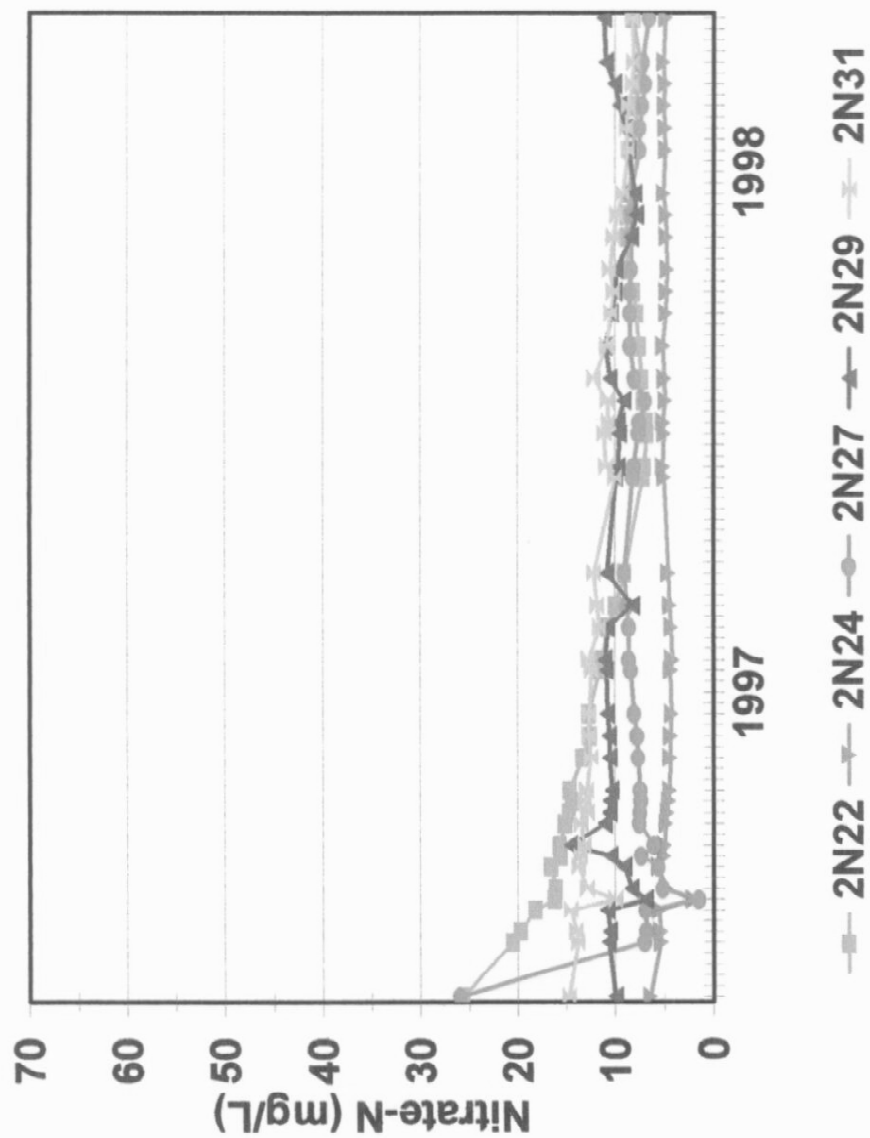


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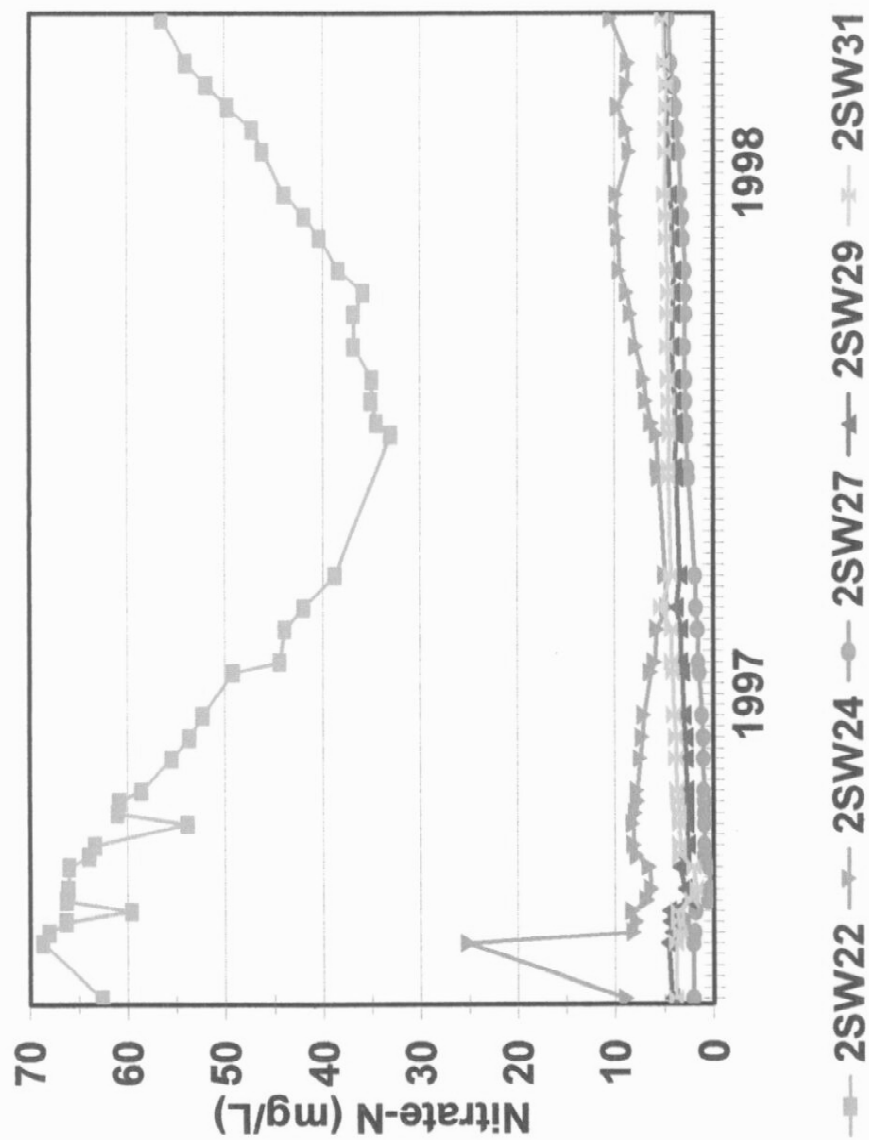


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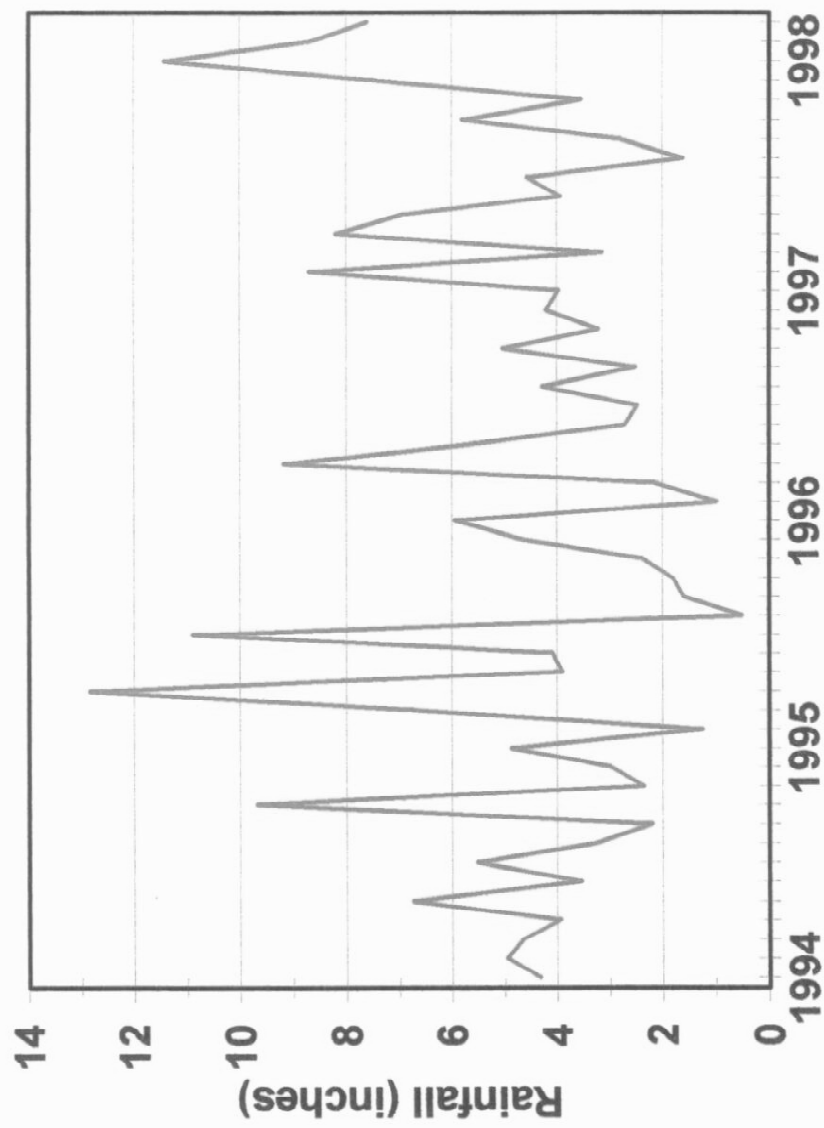


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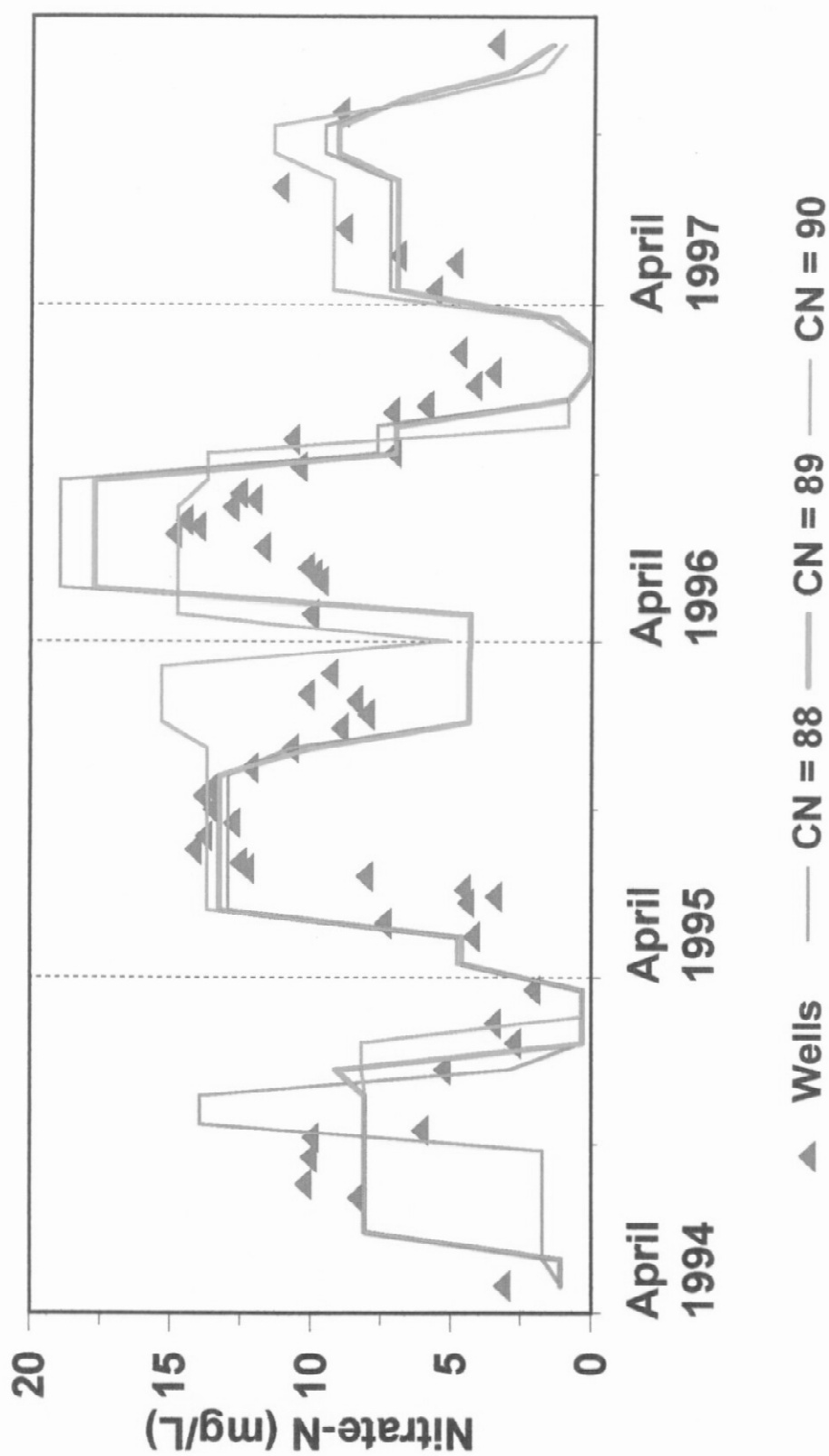


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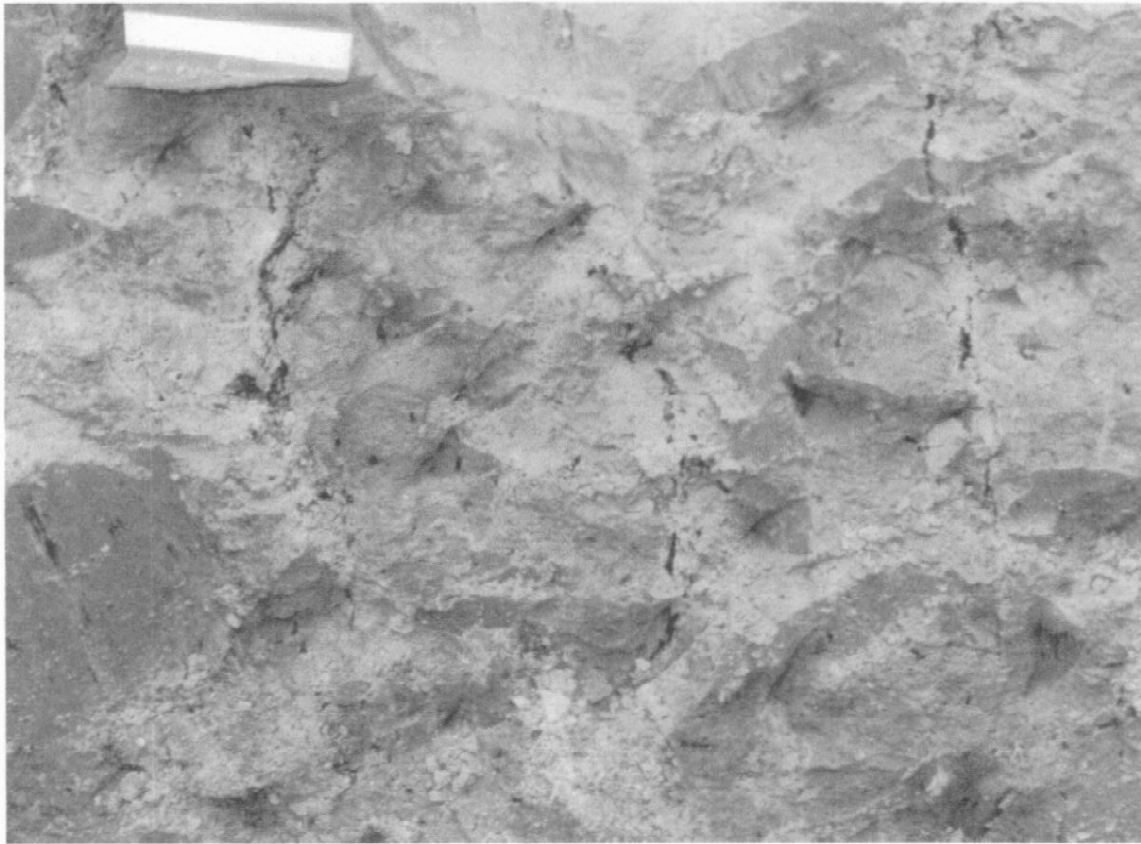


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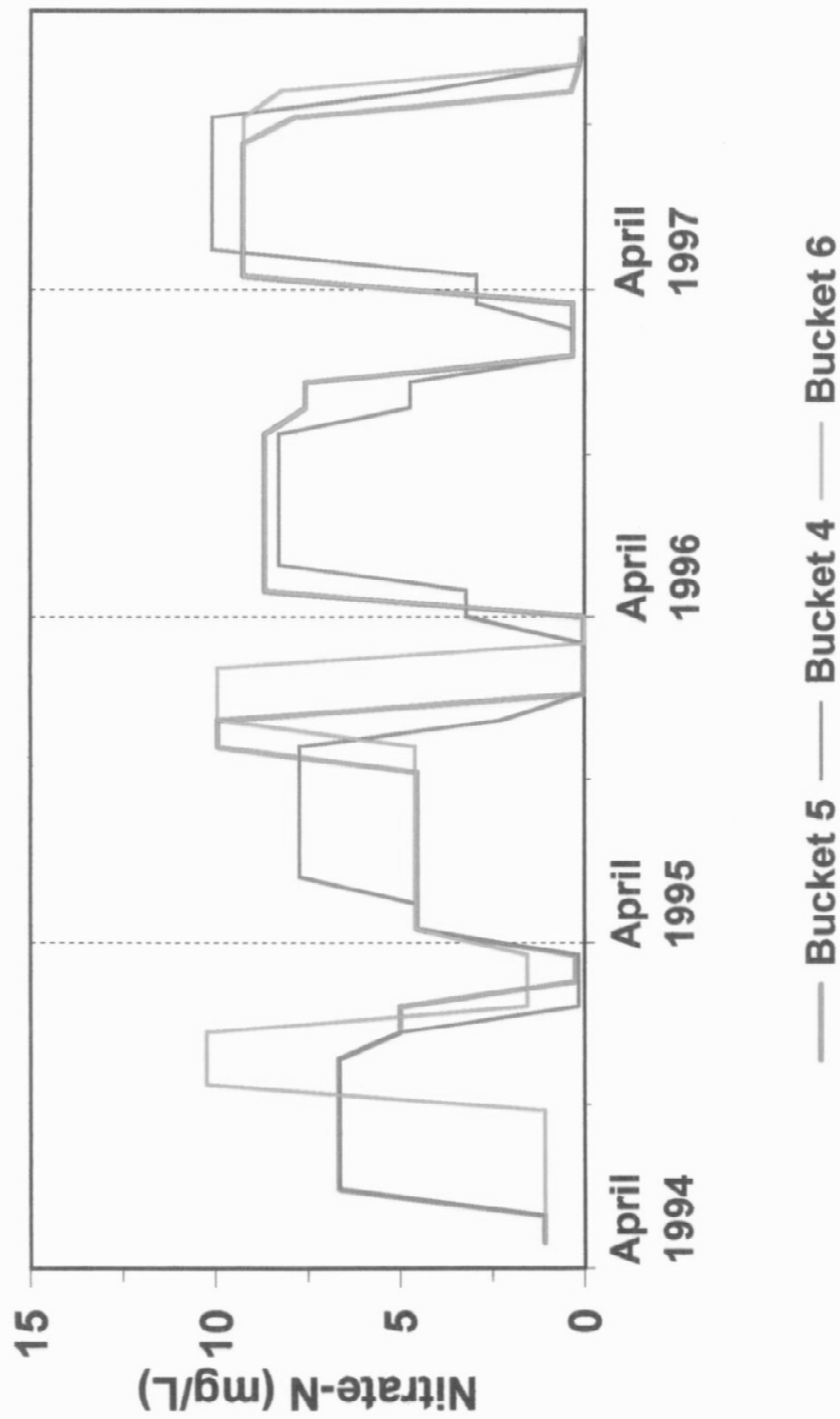


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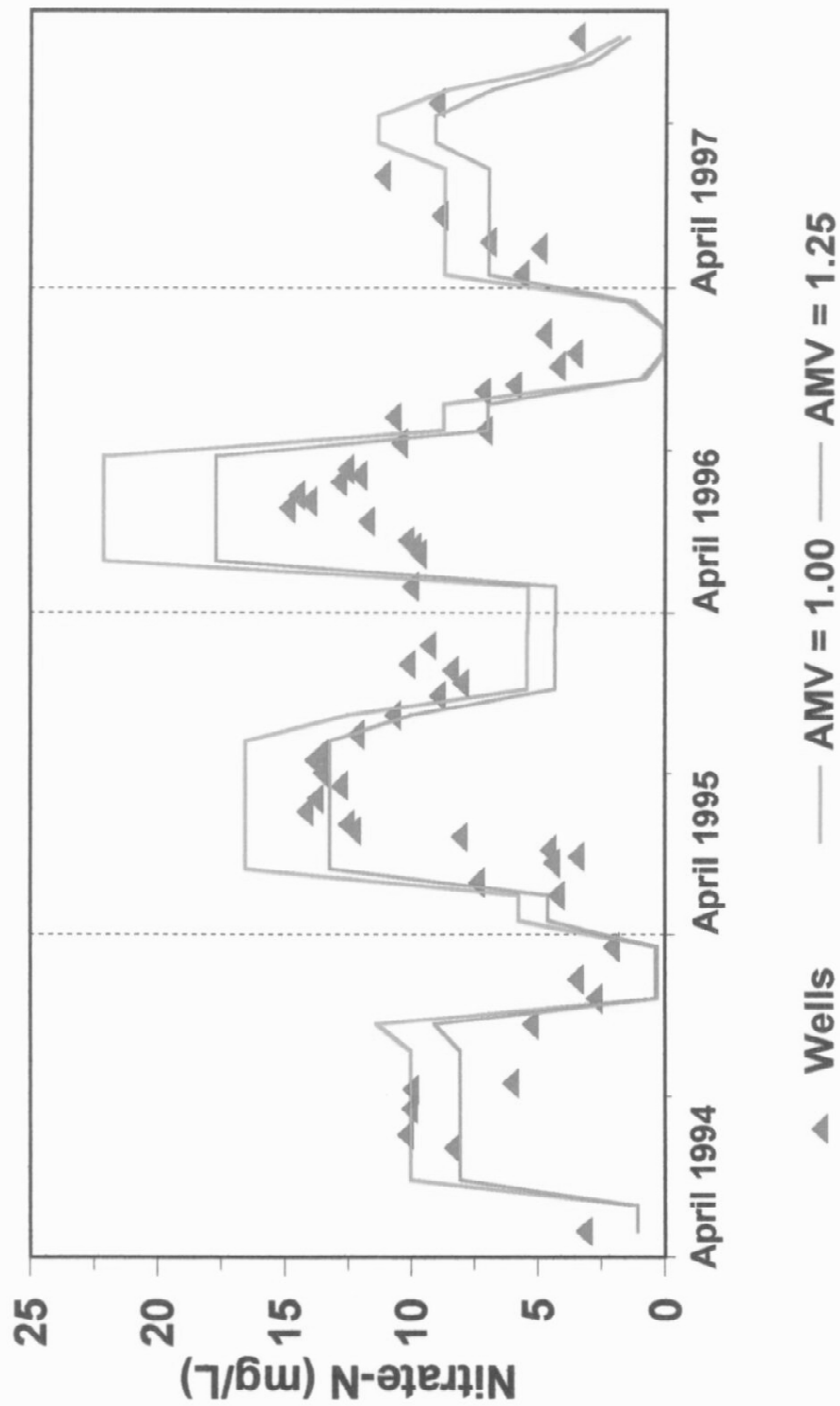


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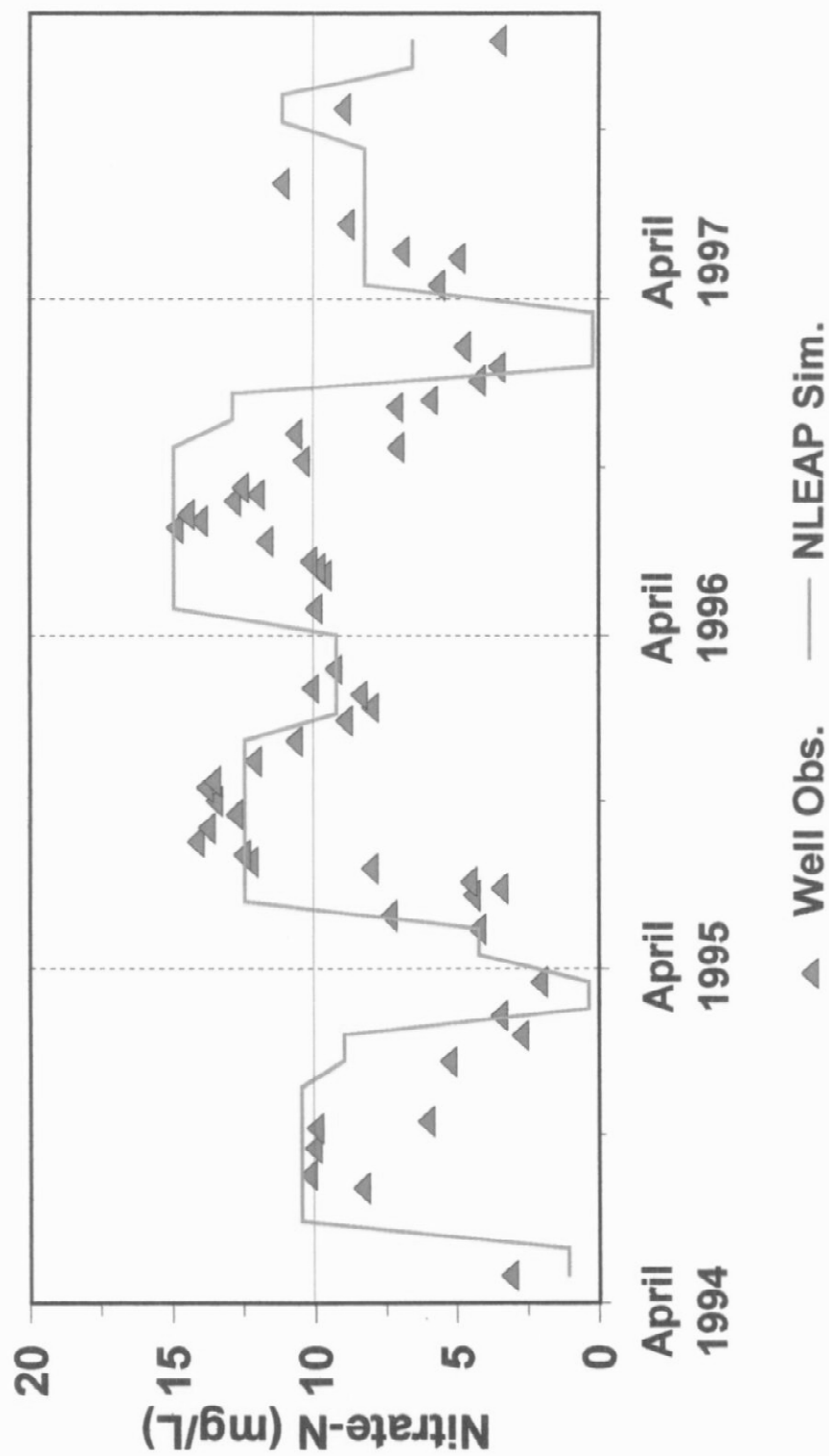


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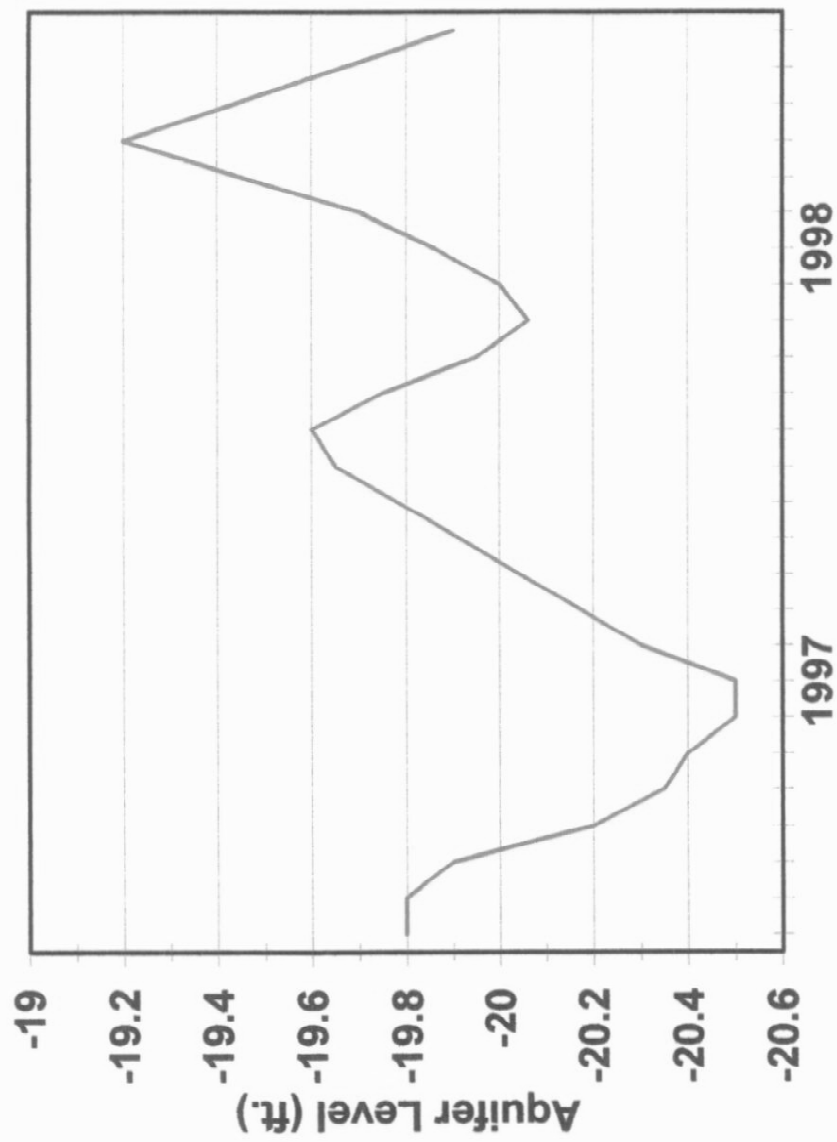


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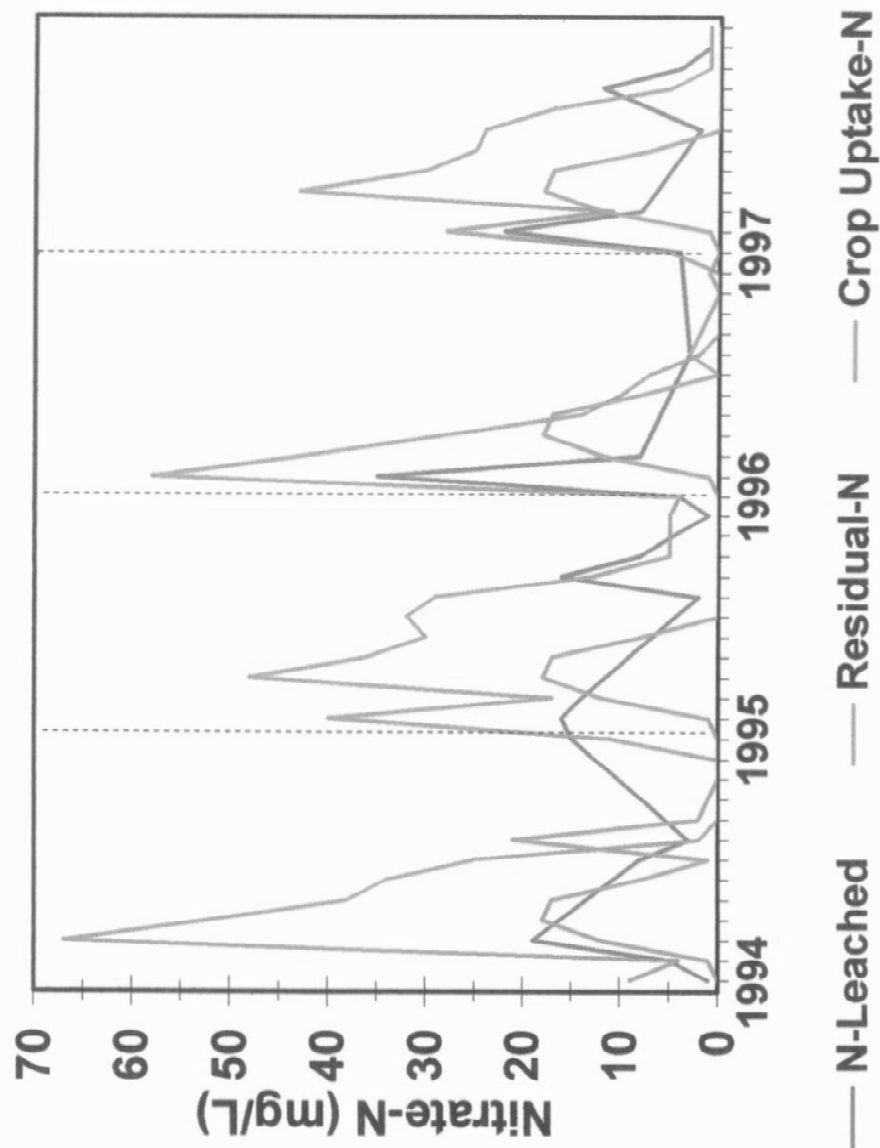


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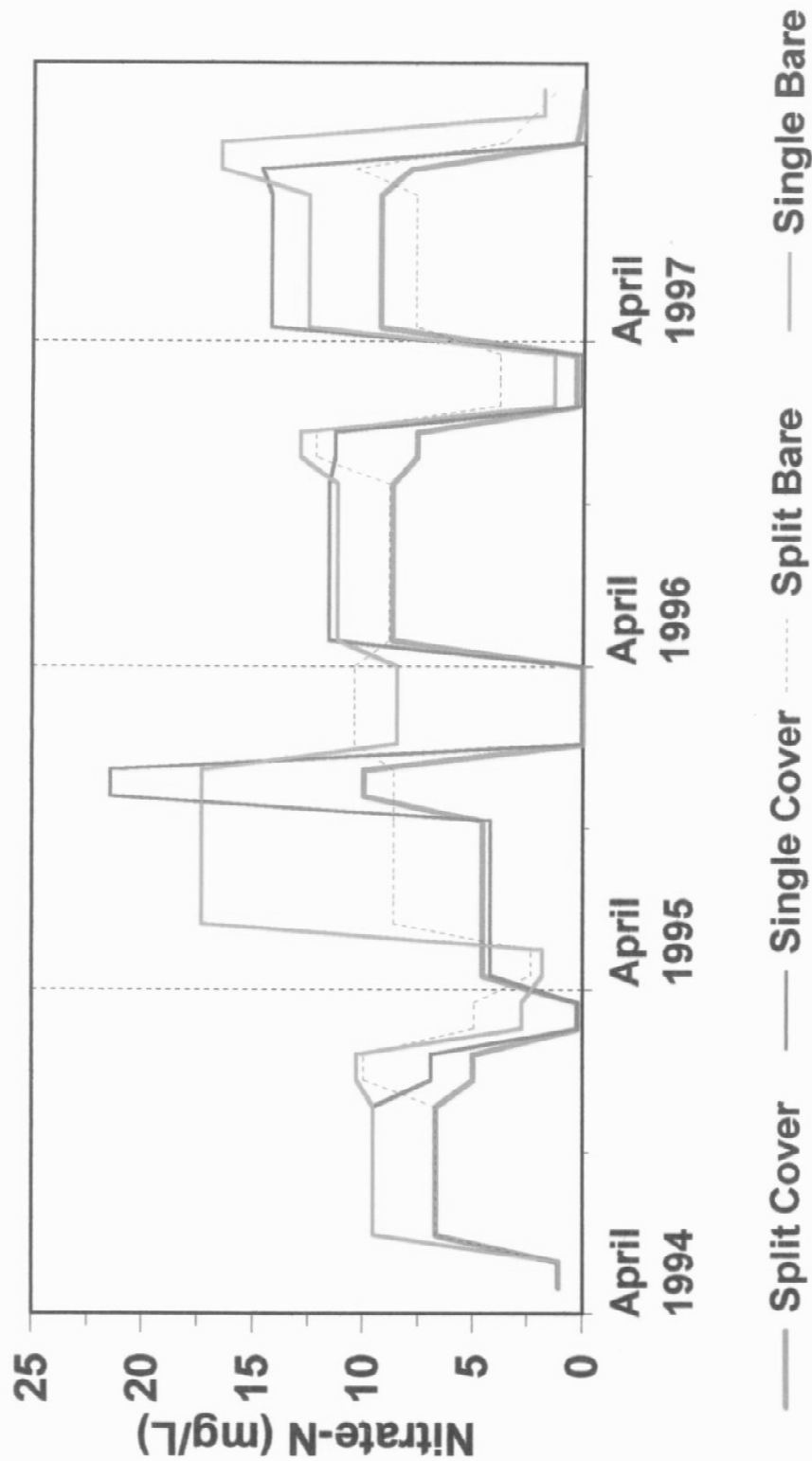


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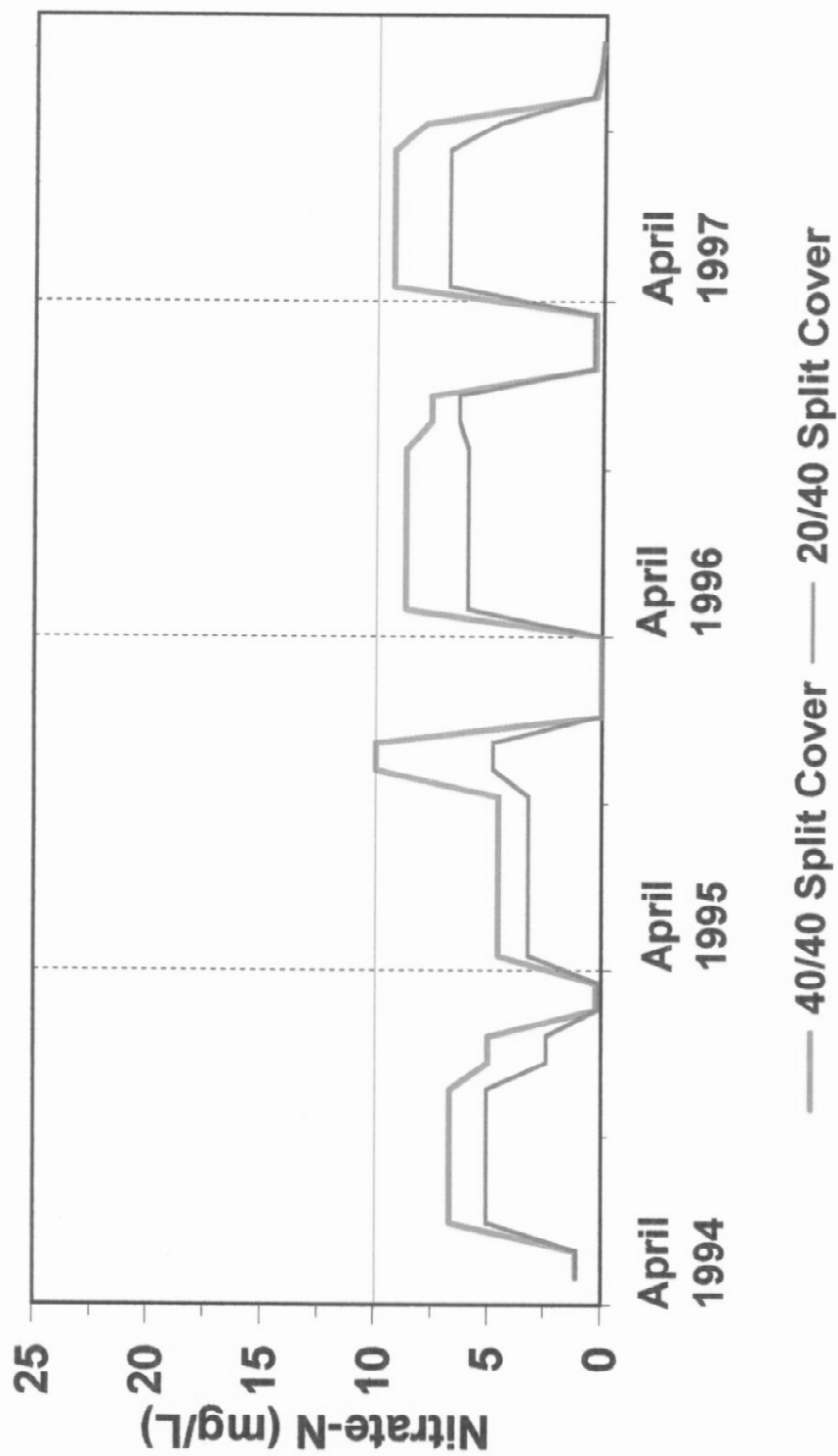


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ATTACHMENT A

Table 1. Specific depth measurements of 20 to 30 foot wells.

Site-Well	Screen Interval	
	Top	Bottom
	(feet)	
1-2	23.1	33.1
1-3	19.5	29.5
1-4	19.8	29.8
1-11	20.2	30.2
2-16	19.8	29.8
2-21	19.8	29.8
2-24	23.3	33.1
2-25	23.5	33.5

Table 2. Specific depth measurements of multi-level wells.

Site-Well	Screen Interval		Site-Well	Screen Interval	
	Top	Bottom		Top	Bottom
	(feet)			(feet)	
1N19	19.5	20.5	2SW19	19.1	20.1
1N22	22.0	23.0	2SW22	21.6	22.6
1N24	24.5	25.5	2SW24	24.1	25.1
1N27	27.0	28.0	2SW27	26.6	27.6
1N29	29.5	30.5	2SW29	29.1	30.1
1N31	32.0	33.0	2SW31	31.6	32.6
1SW19	19.3	20.3	2N19	19.2	20.2
1SW22	21.8	22.8	2N22	21.7	22.7
1SW24	24.3	25.3	2N24	24.2	25.2
1SW27	26.8	27.8	2N27	26.7	27.7
1SW29	29.3	30.3	2N29	29.2	30.2
1SW31	31.8	32.8	2N31	31.7	32.7
1SE19	18.3	19.3	2SE19	19.3	20.3
1SE22	20.8	21.8	2SE22	21.8	22.8
1SE24	23.3	24.3	2SE24	24.3	25.3
1SE27	25.8	26.8	2SE27	26.8	27.8
1SE29	28.3	29.3	2SE29	29.3	30.3
1SE31	30.8	31.8	2SE31	31.8	32.8